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CREW PERFORMANCE DURING REAL-TIME LUNAR MISSION SIMULATION

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SUMMARY

In order to study the performance of a crew in prolonged space flight, a simulation was made of a lunar landing mission beginning with launch from earth and terminating after earth reentry. Three trained test pilots, enclosed in two interconnected mock-ups of a command module and a lunar orbit rendezvous vehicle, flew three realistically simulated missions. Piloting performance was evaluated by comparison of accuracies achieved during the simulated missions with the base-line data obtained during training. The areas evaluated included crew proficiency in normal mission duties, crew alertness to emergency situations, the effects of duty cycles and physical conditioning, and crew psychophysiological reaction. The study showed no decrement in performance of mission tasks with test pilot personnel for confinement periods up to 7 days and the alertness of the crew remained high throughout the mission. It was found that a 26-hour duty cycle with two 4-hour sleep periods was more desirable than a 24-hour duty cycle with one 8-hour sleep period. Because of the onboard exercise program, there was no deterioration of physical condition. Also, medical and psychological tests indicated no psychophysiological stress reaction due to the confinement during the 7-day mission time.

INTRODUCTION

One of the many problems facing crews on future space flights is the length of time required and its effect on mission completion. Results of numerous simulation studies show that pilots can perform various specific space flight control tasks (for example, refs. 1 to 4), but little is known about the effect of the long mission duration on pilot performance during these tasks. Even for the simplest circumlunar mission of the ballistic free-fall type, flight times of about 7 days will be required. Round-trip missions to the nearest planets may require many months or years of flight time depending on the available propulsion systems. In addition to the time element, some difficulties may arise as a result of the small volume available for working and living quarters and the restricted sensory-input environment. It has been suggested that these factors may pose both physiological and psychological problems for the crew.

As pointed out in references 5 and 6, some biomedical studies of the effect of "sensory deprivation" and confinement have been made, and the findings of these studies have been extended as being pertinent to the conditions of space flight. However, doubt may be cast on extending the findings of these studies to future space flights for the following reasons: first, the nonrealistic environment utilized in most of the studies; second, the lack of any criteria for selecting the subjects; and third, the performance of duties which were not applicable to space missions.

In order to obtain data from a study not subject to these criticisms, the National Aeronautics and Space Administration has sponsored a real-time lunar mission simulation using as crew members three NASA test pilots who were enclosed in a realistic spacecraft cabin environment and performed duties applicable to a lunar mission. This investigation was conducted by Martin Marietta Corporation for the NASA under contract NAS-1-1861 and is reported in reference 5, the final report from the contractor to the NASA. Brief reports of the investigations have been presented in references 7 and 8.

The mission duties consisted of representative analog simulated flight-control tasks and also simulated navigational and systems monitoring and management tasks. Two types of lunar landing were studied, the direct landing and the lunar orbit rendezvous (LOR). The direct landing requires the whole spacecraft to land on the lunar surface; whereas for LOR a small vehicle is detached from the main orbiting spacecraft, descends to the lunar surface, and then returns to join the main spacecraft by means of a lunar orbit rendezvous.

The object of this study is to determine whether the stressful conditions of confinement and long-time flight, with the associated restricted sensory environment, would have an effect on the performance of flight-control tasks and other mission tasks. In addition, other factors that would have an effect on crew performance, such as the type of duty cycle utilized and the physical fitness of the crew, were included as study areas.

In order to evaluate crew performance systematically, a base-line set of criteria was established from a preflight training phase. The training phase covered a 10-week interval and included all mission tasks and emergency procedures. In addition, a preflight physical conditioning program and an in-flight physical exercise program were designed for the crew by a professional physical therapist. Also, the crew were given medical and psychological tests during the training phase and after the simulation runs to determine if there were any signs of physiological or psychological stress.

Performance was evaluated from consideration of the following main areas: normal mission duties, including simulated flight control tasks and alertness to emergency situations; evaluation of duty cycles; physical condition of the crew before and after the flights; and the use of various psychophysiological measures as indices of reaction or tolerance to stress.

Three simulated missions or flights were undertaken; the first two lasted 75 hours and the third lasted 168 hours. Two duty cycles were studied; a

24-hour cycle which contained 8 uninterupted hours of sleep and a 26-hour cycle which contained two 4-hour periods of uninterrupted sleep.

SYMBOLS

The British system of units is used in this study. In case conversion is desired, the following relationships may be used:

1 U.S. foot = 0.3048006 meter

1 international nautical mile = 1852 meters (exact)

g	acceleration due to earth gravity, 32.2 ft/sec^2
h	vehicle altitude, ft
$\dot{h}$	rate of change of altitude, ft/sec
F	vehicle thrust, lb
V	vehicle velocity, ft/sec
ΔV	velocity increment during thrusting phases, ft/sec
W	earth weight of the vehicle, lb
x,y,z	coordinates of rendezvous vehicle in right-hand system centered at main spacecraft center of gravity with Z-axis along radius vector from center of moon and Y-axis perpendicular to radius vector, ft
$\dot{x},\dot{y},\dot{z}$	time rate of change of x-, y-, and z-displacement, respectively, ft/sec
θ	vehicle pitch angle, deg
ψ	vehicle yaw angle, deg
ϕ	vehicle roll angle, deg
$\dot{\theta}$	pitch rate, deg/sec
$\dot{\psi}$	yaw rate, deg/sec
$\dot{\phi}$	roll rate, deg/sec

Subscripts:

e error

f final

LUNAR MISSION DESCRIPTION

Trajectory Characteristics

The basic operation used for this investigation was a lunar mission, which included all the phases shown in figure 1, from launch through return reentry into the earth atmosphere and touchdown. Note that both direct and LOR lunar landings are listed, but an actual mission would incorporate one or the other. For the particular mission under consideration, launch from earth was terminated with the vehicle in a 100-nautical-mile earth orbit, where it remained for about an hour before insertion into the translunar orbit. The insertion required an increase in velocity of 10,000 ft/sec. During the translunar orbit, three midcourse corrections were required and the velocity increments used were less than 50 ft/sec. The first two of these corrections took place within the first 24-hour period after translunar insertion, and the third within 12 hours before insertion into lunar orbit. The spacecraft reached the point of lunar orbit insertion after 70 hours with a velocity of 8,300 ft/sec. Achievement of the 100-nautical-mile lunar orbit required a decrease in velocity of 3,000 ft/sec to slow down to the orbital velocity of 5,300 ft/sec. Descent to the lunar surface began 30 minutes later. The landing began with an initial deorbit impulse and the vehicle then coasted down to about 43,000 feet where the final braking slowed the vehicle down to landing velocity. This type of landing trajectory was used for both the direct and the LOR landings. In both cases if the landing phase was aborted for any reason, such as system failures or solar flare warnings, the pilots followed a standardized abort procedure that returned the vehicle to lunar orbit.

Return to earth after a successful landing on the moon began with a launch into lunar orbit, then insertion into a transearth orbit. The ascent from the lunar surface for either type landing was similar except for the rendezvous required in the LOR method. Launch and ascent to the 100-nautical-mile-orbit required about 1/2 hour. Transearth insertion occurred 1/2 hour after orbit attainment.

Three midcourse corrections were required as the vehicle traveled along the transearth orbit before reaching the point of reentry into the earth atmosphere. The reentry covered about one-fourth the earth perimeter, or some 6,000 miles of longitudinal range before touchdown on the earth surface.

Crew Composition

For this mission, the crew consisted of three men: the commander, navigator, and engineer, each capable of performing the tasks assigned the other two.

The work load on the crew included such tasks as flight control, navigation, and systems management and monitoring. The flight-control tasks, which consisted of operating the controls of the spacecraft propulsion in order to maintain its proper speed and direction, were the responsibility of the commander who was in charge of the crew and the spacecraft. The navigator's main responsibility consisted of obtaining star-fix data by means of a sextant device and entering these data in an onboard computer. Systems monitoring and management tasks (engineer's main responsibility during thrusting phases) required the crew to maintain all the systems and subsystems within specified tolerances, detect and correct malfunctions, and perform troubleshooting and corrective maintenance.

EXTENT OF SIMULATION

Simulation Program

In the present investigation, three lunar mission simulations (or flights) were conducted over a period of 6 weeks, allowing a 1-week layoff interval between each flight. This 6-week period was preceded by a 10-week orientation and training period. The first two flights of $3\frac{1}{2}$-day duration simulated the described mission up to the point of transearth insertion (following lunar take-off). The third flight, however, simulated the entire 7-day mission. Each flight was designed to simulate an actual precomputed lunar mission trajectory as closely as possible; however, in order to obtain as much data as possible, the flights deviated from the basic lunar mission sequence in certain instances. This deviation included a closed-loop study of both types of lunar landings: the direct and the LOR with its associated lunar rendezvous. Each of the three crew members performed both types of lunar landings, and each performed an earth reentry. Thus, a rearrangement of the mission times was needed to include the extra flight-control phases and still maintain the proper overall mission time; this was accomplished by omitting some of the translunar and transearth coasting periods. Four NASA pilots participated in the program and they will be referred to as pilots A, B, C, and D. Pilot D participated only as an observing crew member in flight II. Pilots A and B participated in all three flights.

Simulation Equipment

A plan view of the simulation facility is shown in figure 2. This facility is located at the Baltimore Division of the Martin Marietta Corporation. The facility consists of three main areas: the simulation room, control room, and analog computer room.

The simulation room housed two interconnected simulators. The room was air conditioned, light proof, and partially sound attenuated. The main simulator was a mock-up of an Apollo-type command module. The external configuration consisted of a conical forebody with a half-angle of 30°, a base diameter of 166 inches, and a hemisphere of 17-inch radius at the apex. These dimensions gave the simulator approximately 400 cubic feet of enclosed volume. An external view is shown in figure 3. The internal volume provided for a flight deck, sleeping area, off-duty area, toilet, and galley. The flight deck, as shown in figure 4, provided side-by-side seating for the three crewmen in front of the display control panel. Facing the panel from left to right are the positions of the commander, navigator, and engineer, respectively. The section in front of each position was color coded to separate the functions of each crew member, but the entire panel could be monitored from the center position. Along the upper periphery of the entire control panel were located event sequencing lights and malfunction warning lights.

The commander's position provided for maintaining basic flight control. Controls included a throttle for translation and a two-axis side-arm controller and rudder pedals for attitude control. His displays provided an indication of all the pertinent flight variables. Among these were a cathode ray tube (CRT) for special displays, a three-axis attitude indicator, and angular rate indicators.

The navigator's panel in the center served as a standby flight-control area for emergency backup of the commander and, therefore, had redundant attitude indicators and controllers (pitch and roll side-arm controller and yaw rudder pedals) and a special-purpose CRT display. In addition, the center position had access to navigational equipment such as clocks and timers, inertial platform controls, onboard computer controls, communications controls, and an overhead trisextant above which a display of stars and planets was available for obtaining navigational data.

The engineer's panel at the right contained displays which presented information on various onboard systems such as environmental, electric power, and propulsion systems, and indications of radiation and meteorite impacts.

The LOR vehicle simulator was attached to the command module simulator by a 12-foot tunnel, as shown in figure 5. It resembled the cockpit of a one-man aircraft and was used only during the LOR landing and rendezvous phases. A large plexiglass windshield was provided in order to view the rendezvous target moving across a star field that was projected on the wall in front during the rendezvous phase. The display and control panels of the LOR vehicle contained the same amount of flight-control information as the commander's section of the command module simulator panel, but it was arranged somewhat differently.

The control room was located adjacent to the simulator room, where the flights were coordinated and monitored by means of closed-circuit television. In the control room there were 12 consoles used to produce realistic displays on the display and control panels in the simulators. The consoles provided an indication of the meter readings on the display and control panels in the simulators. Also, the consoles were equipped with means to vary the meter readings on the simulator display and control panels.

A total of 262 operational amplifiers were used to program the flight-control phases of the simulation on the analog computing equipment.

TASK DESCRIPTION

Computation Techniques

The various flight-control tasks were mechanized by a closed-loop analog computer simulation of each of the phases shown in figure 1. In these tasks, the pilot observed the display on the display and control panel and responded with inputs to the throttles and attitude controllers. These control inputs were fed to a set of perturbation equations which determined the simulated vehicle motion about a predetermined trajectory for all mission phases except the braking part of lunar landing and rendezvous.

For the braking part of lunar landing a three-degree-of-freedom simulation was programed, providing two translational degrees of freedom in the vertical plane and one rotational degree of freedom about the pitch axis. The pilot could control yaw and roll, but these were uncoupled and did not affect the trajectory. The rendezvous equations allowed three degrees of freedom in translation, with the vehicle attitude stabilized.

Flight-Control Tasks

The pilot's job during earth ascent was to maintain the vehicle attitude in yaw and roll at zero while following a pitch program and also to stage the launch vehicle at the proper times. During translunar insertion, midcourse correction, lunar orbit insertion, lunar deorbit, lunar ascent, and transearth insertion, the pilot's task consisted mainly of controlling the proper vehicle attitude while applying thrust to achieve the required velocity changes using the proper engine management. The CRT displays used in these phases are shown in figures 6(a) and 6(b). After the first two flights, a change in the display was incorporated and ΔV corrections were obtained from a digital readout.

The simulation of the lunar-landing phase was based on that of reference 1. The same nominal trajectory was used for both the direct and the LOR landings, although vehicle dynamics and engine combinations appropriate to each were used in their respective simulations. The main vehicle had a rate-command attitude control system, whereas the LOR vehicle had an acceleration attitude control system. The trajectory was initiated at lunar deorbit and consisted of an elliptical coasting path for 25 minutes until an altitude of 43,000 feet was reached. At this altitude the vehicle velocity was 5,535 ft/sec and the flight-path angle was -4.55°; here the pilot took over the controls again for the final braking and landing. Also, the maximum thrust-weight ratio was 0.672 for both vehicles, but the LOR vehicle was more responsive in attitude than the main vehicle. The nominal altitude-velocity curve of the final braking and landing is shown in figure 7. During this braking maneuver, the pilot's CRT display (fig. 6(c)) consisted of a static plot of the nominal altitude-velocity curve and a pitch-error and range-rate-error indication. The actual velocity and altitude of the vehicle were shown by a dynamic dot that followed the curve as long as the pilot maintained zero pitch-angle error. If the dot drifted away from the curve, the pilot then disregarded the pitch-error indication and applied the proper controls to bring the dot back to the curve. This procedure was followed until a landing velocity of 160 ft/sec was reached. The commanded pitch angle had been a very slow rate but, when 160 ft/sec was reached, a rapid rate of pitch to 90° was commanded. During this time the landing velocity of the vehicle was reduced to 100 ft/sec at about an altitude of 1,000 feet. From this point to touchdown an altitude indication appeared at the right of the CRT and the pilots made a vertical descent to touchdown. The last phase was completed at a maximum value of F/W of 0.294.

In order to determine the pilot's ability to recover from an emergency situation, an abort procedure was designed for both the main and excursion landings. The crew were given practice abort runs during the training phase. During the flights, several of the landings became surprise aborts because of simulated system failures.

The main vehicle abort procedures were as follows:

(1) Cut the lunar-landing-module engines

(2) Separate the lunar-landing module

(3) Ignite the service-module engines

(4) Pitch to 100° and roll to 160° (160° was used instead of the desired 180° because of computer limitations)

(5) Complete the aborted flight as though flying a normal ascent trajectory

The LOR vehicle abort procedures were as follows:

(1) Apply full thrust

(2) Pitch to 100° and roll to 160°

(3) Complete abort trajectory as if flying a normal ascent trajectory

In the simulation of the rendezvous phase, the LOR vehicle was attitude stabilized and was provided with rockets for translation control in both directions along each body axis. Also, two levels of thrust were available providing 0.1 g or 0.01 g acceleration in each direction. The same initial conditions used for both the base-line and the flight runs were as follows: the LOR vehicle was 30,000 feet below, 30,000 feet ahead of, and 5,000 feet to the side of the orbiting vehicle which was passing overhead at a relative rate of 300 ft/sec. The orbiting vehicle first appeared to the pilot as a flashing dot in the projected starfield in front of the simulator as he looked out the windshield. His first task was to center the dot in his field of view. When this was accomplished, his CRT was activated and used for the remainder of the flight. The CRT displayed the position of the orbiting vehicle in the horizontal plane as a dot relative to a set of crosshairs, whereas growth of the dot into a circle provided vertical displacement information. Rates were obtained by rate of change in displacement of the dot and rate of growth of the dot into a circle. The CRT display actually represented a periscope view and two simulated lens settings were available which corresponded to a 45° and a 2° field of view. The 2° setting allowed very sensitive position indications and was used only when the dot was centered in the crosshairs. The pilot's task was to center the dot in the crosshairs, which indicated the orbiting vehicle was directly overhead, and then to keep the growing circle centered as he approached the orbiting vehicle vertically. In order to provide the accuracy required for the docking phase, when the vertical displacement became less than 150 feet, the pilot's readings were confirmed by ground monitors because of onboard display limitations.

The reentry trajectory followed was a skip-glide type as shown in figure 8. This trajectory was generated by means of a digital simulation program that used a predictive guidance scheme (ref. 2). The initial conditions assumed were velocity, 36,000 ft/sec; altitude, 400,000 feet; and flight-path angle, -7°; and the vehicle had a lift-drag ratio of 0.5. There was no initial lateral range error assumed, and the touchdown point was 5,900 international nautical miles away. To achieve this range, the guidance scheme required a skip accompanied by several roll maneuvers. These roll maneuvers consisted of reversing the roll angle at four specified times along the trajectory. In order to follow this trajectory, the pilot had to maintain the proper altitude and rate of change of altitude. To aid in accomplishing this task, the pilot was given the CRT display shown in figure 6(d). In the middle of the display an indication of the altitude error and altitude rate error was given. Around the periphery the command roll angle was presented as a small circle and the true roll angle was presented as a dot. A cursor was presented along the horizontal line at the lower part of the screen to give the pilot an indication of an approaching roll reversal command.

The pilot's task was to follow the commanded roll angle while maintaining trimmed attitude. Pitch and yaw were uncoupled but provided a piloting task. If an error was accumulated in altitude or altitude rate, the commanded roll angle was ignored and the vehicle was rolled until the errors were nulled, then the pilot resumed the commanded roll angle.

Other Mission Tasks

The navigational tasks were simulated by taking readings of star positions through a trisextant shown in figure 9. A slide projector was used to project a realistic starfield on a screen above the trisextant. The readings were entered into a modified addition machine to simulate entering the data into an onboard computer.

The systems monitoring and management tasks were simulated by activating meters on the flight panel from switches in the control room. Switch positions in the control room provided meter readings on the panels and thus variations in different subsystems could be simulated. The crew could respond by adjusting various controls at the panel to maintain proper meter readings.

Duty Cycles

The duty cycle utilized during a mission of this sort could aid in alleviating effects of confinement. The effects of two duty cycles were studied during this program. As shown in figure 10, the first was a 24-hour cycle which included an 8-hour uninterrupted sleep period and the second was a 26-hour cycle with two 4-hour uninterrupted sleep periods.

The basic arrangement of the duty cycles was for one man on duty, one off duty, and one asleep at all times except during thrusting phases and other instances in which two, or all three, crew members were required to be on duty at the same time. Thus, the general form given in figure 10 could not be followed at all times. Some factors that were included in the design of the cycles were an attempt to have an off-duty period before and after each sleep period, duty periods of not longer than 2 hours at a stretch and a reasonably repeatable cycle.

Physical Conditioning

The crew maintained a physical exercise program to prevent performance and physical deterioration due to reduced physical activity during the confined periods. Some of the physical effects that have been noticed in previous confinement studies (ref. 6) are loss of leg strength, failure or impairment of bowel action, loss of appetite, increase in tension, pain in lower back, pain in upper back from positional fatigue, and cervical pain.

The physical exercise program was designed by a professional physical therapist to combat these symptons. The program consisted of two parts: preconditioning and the in-flight program. The preconditioning program started 6 weeks before the first flight and consisted of swimming, tumbling, running, weight lifting, and calisthenics; by the time of the first flight, the pilots were considered to be in excellent condition. The onboard program was carried out by means of a bungee-type device which, with suitable restraint, would appear to be practical under zero "g." The device is shown in figure 11. There were 11 exercises, 8 with the bungee device. The actual exercises used are described in appendix A.

Psychophysiological Tasks

The crew were given thorough medical, psychological, and psychiatric examinations 6 weeks before the first flight and immediately after the first and third flights. This examination included the Harvard step test (appendix B) to measure physical endurance. A brief medical exam was given after flight II.

In addition to their normal mission duties, the crew were given several other duties which were used to determine their psychological and physiological reaction to the flights. These tasks could possibly measure effects not obtainable by using the more complex tasks of normal mission duties, and they would be comparable with data from biomedical studies.

The crew were given two behavioral response tasks to provide an indication of stress, if it existed. The tasks were designed to test reaction time and time estimation.

The crew were given the task of collecting their own urine samples and of measuring their own blood pressure. The urine samples were analyzed by laboratory technicians to determine the excretion level of 17 hydroxycorticosteroids, as an indication of stress. It represents the breakdown of adrenal products that are introduced into the blood during times of physiological and psychological stress. These are also used to determine the degree of adaptation of the crew to the duty cycle. The blood-pressure measurements were made every 8 hours during the flights by the crew themselves to determine the systolic pressure. An elevated systolic pressure is known to occur during intense excitement and anxiety. On the other hand, the lack of body movement within the simulator might depress the blood pressure.

CREW SELECTION

As mentioned in the introduction, in some of the confinement studies in which physiological or psychological problems have been encountered, there were few or no criteria for personnel selection. Consequently, some of the subjects were in poor physical condition and had no real motivation for good task performance. This situation is in contrast to what is expected of a trained astronaut crew. Results obtained with these untrained subjects have, in some cases, been quite unexpected in that the subjects had hallucinations, muscular pains, and other effects. The publicity awarded these results has cast certain doubts on man's ability to perform well in confined areas over prolonged periods.

In order to approach this problem area more realistically, the four crew members participating in the NASA-Martin experiment were all NASA research pilots. These pilots were mature, experienced, and well-motivated, their average age was $34\frac{1}{2}$ years and their average flight time was about 4,000 hours; each had flown at least 40 different types of aircraft. Three of the pilots comprised the actual crew while the fourth acted as primary capsule communicator. No compatibility tests were used in crew selection.

CREW TRAINING

The overall preflight training program began 10 weeks before the first flight with a 5-day orientation and training meeting which consisted of a series of lectures on the mission concept, operation of the equipment, and flight time history. During this time, the crew were given several training and flight manuals on description of the simulated mission, crew-equipment operating procedures, flight plans for the first flight, and malfunction procedures. After this meeting, the crew returned to their home bases to study the manuals. At the beginning of the fourth week another 5-day meeting was held to review the procedures and familiarize the crew with flight displays and obtain practice on the rendezvous phase. At the end of this week the crew again returned to their home bases until 3 weeks before the first flight. During the intervals between meetings, several 1-day trips were made by the crew for practice.

During the 3 weeks before the first flight, the crew were given practice on all tasks, and base-line data were recorded. The tasks that required the most training were the flight-control tasks. Table I shows the number of flight-control runs completed by each crew member.

During the training period, the crew developed an in-flight check list for their own use during the flights. This list contained the sequential operating steps of all the phases and was used extensively by the crew during the flights.

RESULTS AND DISCUSSION

The results of this investigation are based on a comparison between flight and base-line data to determine whether the crew displayed any deterioration in performance of mission tasks. The comparison was extended to include the effects of duty cycle and physical conditioning and to determine whether the crew underwent any psychophysiological stress.

Operating Conditions

Generally, the flight results indicated no degradation in pilot performance resulting from the stressful conditions of the missions; however, there were some few instances in which a pilot's performance during a flight was not quite as good as his preflight performance. This could be attributed to the fact that preflight tasks were made up of separate mission phases, whereas the flights covered the total mission, and time did not permit intensive pilot training for the combined phases as an integrated mission. This pertains particularly to the detailed mission and task procedures. It was felt that a more intensive training program, as certainly would apply to an actual mission, would rectify this problem. In addition, the pilots had to use relatively poor instrument displays and hand controllers which also could not be optimized because of the lack of time. As a result of the display and controller limitations, the ability of the pilots to obtain certain flight conditions was determined more by these limitations than by pilot capability. Thus, the data presented do not represent optimum values but do provide the desired comparison between preflight and flight data.

Flight Control

The crew's performance during each of the flight-control phases was evaluated by means of the variables given in table II. The early mission phases from translunar insertion through lunar deorbit, as well as the return phases of lunar launch, transearth insertion, and midcourse correction, all used ΔV_e as the evaluation variable. Since each of these phases occurred in ascending order throughout the mission, a progressive increase in ΔV_e would be expected if a degradation in pilot performance were present. However, no such trend was noted. In fact, in some cases better results were produced after 3 days of flight time than had been obtained after 3 hours. Table III shows the average values of base-line and flight ΔV_e for the phases discussed.

The braking phase of the lunar landing was the most difficult single phase of the mission and required the greatest amount of pilot training. The first attempt to simulate this phase utilized a CRT display that did not include a velocity-altitude curve. It was found that successful landings could not be consistently obtained; therefore, the display of figure 6(c) was incorporated as the final display. Although $\dot{x}_e$ was presented on the final display, it was not used by the crew members because it was incompatible. Thus, landing at a preselected point was not considered as part of the task. The touchdown conditions tabulated in table IV show, in general, that the flight results were as good as, or better than, the preflight results. These data also show that better touchdown conditions were obtained with the main vehicle than with the LOR vehicle. Since both vehicles used the same thrust-weight ratio and the crew members preferred the attitude response of the LOR vehicle, the difference in results must have been due mainly to the poor scan pattern and instrument readout capability, as well as acceleration control, of the LOR vehicle. Pilot C had more difficulty with the LOR landings than pilots A and B because he had less experience at the task since he was not present during the first attempt to simulate the lunar landing and he was less familiar with the manner in which the flight variables were displayed. Although the flight results of pilot C appear unsatisfactory, they were within his preflight averages. In the direct landings, however, all pilots did equally well. An analog recording of the flight III direct landing for pilot C is shown in figure 12.

Four of the flight lunar landings were surprise aborts imposed in the form of simulated system failures. The particular landings aborted were one main and one excursion landing during flight I and one main landing in each of flights II and III. They all occurred below 4,000-foot altitude with a velocity less than 1,500 ft/sec and were all completed successfully. Figure 13 shows the aborted run of flight III, which was representative.

The results of the base-line and flight runs for rendezvous are shown in table V. The range value in the table represents the relative displacement of the two vehicles in the horizontal plane as the excursion vehicle reached the altitude of the orbiting spacecraft. The data show that in general the flight averages were as good or better than the preflight averages. The higher flight averages of total time by pilots A and C were accompanied by much lower total impulse flight averages. This is not considered pilot performance degradation but rather is consistent with previous rendezvous study results wherein fuel use and time were inversely proportional. Pilot B did not appear to follow this trend; however, if the preflight I and flight I data are neglected assuming pilot B had not optimized his method, then the preflight total impulse average would become 113,326 lb/sec and the average total time would become 12.5 minutes. The flight averages become 112,014 lb/sec for total impulse and 13.6 minutes for total time; with this assumption pilot B also followed the trend of pilots A and C. Figure 14 shows a three-dimensional plot of flight III rendezvous for pilot C.

The reentry maneuver was evaluated on the basis of the integrated attitude error and the integrated altitude error weighted with velocity throughout the entire flight and also $\dot{h}_e$ at the beginning of the first skip out. Table VI shows the results of several data runs and the results of flight III. These results show some higher flight integral values than preflight values which might seem to indicate poor performance; however, this was not considered degradation in performance but rather the normal variation in pilot performance. Further indicative that no degradation was experienced are the low values of $\dot{h}_e$ which are as good as could be expected, considering the instrumentation and the short time spent in this portion of the simulation.

Other Mission Tasks

The flight navigational data were not usable because the star projector did not aline the star slides consistently, thus causing different readings from run to run.

The systems monitoring and management tasks required approximately 30 percent of a crew member's total time in the simulator and this amounted to about two-thirds of his actual time on duty. This type of extended monitoring is probably the task that is most sensitive to sensory deprivation or confinement and any performance degradation would be more apt to develop while performing this task; however, performance degradation was not noted.

The crew's performance of operation procedures has already been mentioned to some extent concerning momentary forgetfulness; however, in general the performance was extremely good. With the exception of some of the flight-control procedures, only minor errors were made in mission procedures - such as, the use of the incorrect mode of the inertial platform, failure to switch from earth reference to moon reference at the proper time, and failure to level the main vehicle after lunar touchdown. As with the flight-control tasks, it was decided that more training would eliminate these minor errors.

At certain times during the flights, checks were made to determine the systems status. System checks were made before and after each flight control phase to determine the operational capability of the vehicle, and log checks and entries were made every 4 hours during the coasting periods. The log checks were extensive and practically every meter reading and switch position was written down at this time. These checks were also monitored at the control room consoles and recorded. No mistakes were made but one or two readings were omitted.

At random times during the flights, several malfunctions were introduced. Some could be corrected by merely adjusting a meter, whereas others required the use of a troubleshooting logic for correction. The pilots always recognized the particular malfunction quickly and performed the proper correction regardless of the corrective procedure required.

Duty Cycles

The results of flight I showed no direct effect upon crew performance due to the duty cycle. In reference 7, members of the crew stated that the last few duty hours of the 16-hour waking period were very tiring. Eye fatigue was noticeable, and general boredom sat in from long hours of panel monitoring. Because of eye fatigue and boredom, the crew found it difficult to focus their eyes on one spot and very easy to stare at the panel - looking but not really seeing. In addition, they found it difficult to sleep the full 8-hour sleep period. The average uninterrupted sleep was 4 hours, with the remaining 4 hours spent catnapping or trying to sleep. After 2 days under these conditions the pilots became very tired and this was noticed by the examiners after flight I. Several factors were suspected of contributing to the sleeping problem: noises associated with the simulation such as communications (ground-to-crew and crew-to-crew), warning horns, air-conditioning compressor, movement of crew members about the simulator; variation in temperature; and uncomfortable and restricted sleeping area. As to the structure of the duty cycle, the crew felt that long sustained duty periods in excess of 4 hours made the monitoring task difficult. Also, they felt that the 1-hour off-duty period after a sleep period is definitely required.

The 26-hour cycle used in flight II, featuring 4-hour sleep periods separated by 9-hour waking periods, was found to be much more desirable. As a result, the 26-hour cycle was used for flight III, and at the end of both flights II and III the examiners found that the crew showed no evidence of fatigue or irritability as they had at the end of flight I. Again there was no direct effect of duty cycle upon crew performance; however, since the members of the crew were more rested, this cycle aided them in maintaining their performance during the monitoring periods. Another point of interest is that the pilots had not been given a chance to adapt to the duty cycles prior to the flights and they apparently did not adapt during the flights as indicated by the consistent pattern in variation of steroid levels, but this did not seem to have any effect on their performance.

Thus, it would appear that off-duty periods are highly desirable after sleep periods. Two-hour duty periods help to maintain high monitoring proficiency. Strict adherence to a particular cycle is not necessary and allowances can be made for mission tests. Finally, preadaptation to a particular cycle does not appear to be required.

To combat the boredom of the long monitoring periods, background music was available. No detrimental effects of monitoring capability was noticed; in fact, the crew members believed the music aided a great deal in combating boredom and thus felt they were more alert at the panel. In an actual space mission the boredom of the simulation would most probably be replaced by a higher degree of motivation and possibly anxiety. Nonetheless, the crew felt that background music would also be an asset in an actual mission for off-duty periods and long coasting periods.

Physical Conditioning

Table VII gives the physical conditioning evaluation of the crew prior to and after flight II. These results, in agreement with data recorded on flight I (not shown), show no detectable decrement in physical conditioning after flights of $3\frac{1}{2}$ days. The physical evaluation for flight III was based on the Harvard Step Test and table VIII shows that there was no deterioration after 7 days of confinement.

The exercise schedule for flight I consisted of four 15-minute exercise periods per day. The crew decided shorter more frequent exercise periods were preferable; thus the flight II exercise schedule called for 5 minutes of exercise every off-duty period. However, during the flight the schedule was revised at the request of the crew to 5-minute exercise periods every other off-duty period. In flight III, 8-minute exercise periods were scheduled for every other off-duty periods.

The program was designed to develop and maintain endurance rather than strength in order to combat the physical ailments associated with confinement. The program succeeded in this aim, and it should be pointed out that a less physically fit crew may have developed back and neck pain, and these might have affected their performance. Thus, the physical exercise program is believed to help prevent performance deterioration, and the extent of exercise needed to maintain good condition once it has been obtained is defined by the final schedule that was used. The crew themselves thought that the physical exercise program was worthwhile.

Psychophysiological Tasks

The results of the reaction time and time estimation tests showed no change in pilot performance during the flights. The χ^2 test was applied to all the data, but no significant statistical trends could be obtained.

A corticosteroid analysis revealed that the pilots maintained their normal diurnal variation in the concentration of 17 hydroxycorticosteroids in urine samples through flights I and II. The flight II data are shown in figure 15 and the lack of interruption of the natural duty cycle is surprising even though a 26-hour duty cycle was used. No elevation of the steroids levels indicated a lack of stress due to the confined conditions.

Blood-pressure measurements revealed that generally there was a lack of unusual excitement or anxiety throughout the flights. One exception is the high reading for pilot B that occurred at the 163d hour of flight III as shown in table IX, which gives blood-pressure measurements taken during flight III along with mission time. The high reading was attributed to general excitement just prior to his commanding the first reentry maneuver.

There were two calorie levels used during this investigation, an 1,800-calorie diet for flights I and II and a 1,500-calorie diet for flight III.

Prepared meals were supplied daily without disrupting the confinement. They were stored in a refrigerator, then warmed at mealtime.

Body weight losses averaged $1\frac{1}{2}$ pounds per man during flights I and II, whereas the loss averaged 8 pounds per man during flight III. This loss in weight may have been partly due to dehydration, and the 1,500-calorie diet may have been a little too stringent.

Finally, the medical and psychological evaluation revealed that the crew experienced no medical changes other than the loss of weight and no changes in personality due to the confinement.

CONCLUDING REMARKS

The confinement, restricted sensory environment, and long mission duration did not adversely affect overall piloting performance. However, there were some few instances wherein a specific task was not performed quite as well during the integrated mission profile as it had been performed as a separate task during preflight. These few instances mainly involved procedural errors. Time did not permit the intense training of combined mission phases that would have rectified this problem. Also, time did not permit optimization of instrument displays and controllers which would have decreased the heavy workload imposed on the pilots by certain mission phases. Thus, to insure maximum performance during this type of mission, it would be necessary to include use of optimized instrument displays and hand controllers, as well as intensive initial training in flight control and procedures as separate tasks and as an integrated mission profile.

The alertness of the crew remained high throughout the mission, and when faced with a system malfunction or emergency, they always responded quickly and returned the system to normal operation.

A 26-hour duty cycle with two 4-hour sleep periods was found more agreeable to the crew and more adaptable to the demands of the trajectory than the 24-hour cycle with one 8-hour sleep period.

There was no degradation in physical fitness of the crew during the flights. This was primarily due to the physical conditioning of the crew prior to the start of the flights and the onboard exercise program conducted during the flights. The onboard exercise program required a total of 30 minutes per day.

The results of numerous different psychophysiological tests on the crew indicated no abnormal stress reaction due to the prolonged confinement of the mission.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., February 17, 1964.

APPENDIX A

EXERCISE PROGRAM

Preflight Exercises

The exercises described in this section were used to condition the crew before the flight.

Jumping jack.- The jumping jack was used as a general warm-up exercise. The subject stood erect and jumped, simultaneously spreading the legs and raising the hands through an arc overhead, then jumped again to return to the starting position. This exercise was repeated 100 times.

Rope jumping.- Rope jumping was used for a general warm-up exercise, leg exercise, and respiratory conditioning. The usual form was used for the following four variations: jumping with both feet, one foot, the other foot, and stepping. Each variation was done for 15 seconds with a rest period between each.

Tiger stretch.- The tiger stretch was used to strengthen back and abdominal muscles to aid in prevention of back pain and faulty elimination. The subjects began on hands and knees and moved arms forward keeping knees in place and hollowing the back, then moved arms towards the knees arching the back. It was repeated 5 times initially and increased to 10 times.

Front and back bridges.- Front and back bridges were used to strengthen neck muscles, as an aid in prevention of cervical pain. The front bridge was started on the hands, knees, and forehead. The knees were raised and the body weight was supported on head and feet (the hands were used initially). Back bridges were performed on the back and the body weight was supported on the back of the neck and legs. Initially each one was repeated 2 times, then increased to 5 times.

Front rolls.- Front rolls were used to stretch back muscles and aid in prevention of upper and lower back pain. The front roll began by squatting with hands on the mat, chin to chest, and supporting body weight on the back of the neck. At the start of roll the subject grabed his ankles and kept in a ball as much as possible. This was repeated 5 times initially and then increased to 12 times.

Push-ups, leg lifts, chin-ups, sit-ups.- Push-ups, leg lifts, chin-ups, and sit-ups were used for general conditioning of arms, legs, and abdominal muscles. These exercises were performed with the usually accepted form and the repetitions were determined by each individual.

Swing bell exercise.- The swing bell exercise was used to strengthen the muscles which act to balance the body as a means of counteracting positional fatigue. The exercise utilized a 15-pound bar bell with the weight held between the hands instead of outside as is done normally. All swing bell exercises were performed in the same position with the subject on his toes and with the feet spread a little less than shoulder width. The knees and hips were flexed to put the body in a starting position of precarious balance so that the subject had to struggle to maintain an upright position. The first exercise from this position consisted of swinging the weight from the thigh position overhead to the back of the neck and then returned to the thigh position. This strengthened the muscles of anterior-posterior balance. In the second exercise, the subject swung the weight in a circular motion overhead, keeping the arms relatively straight. Then the circular motion was reversed. This was to strengthen muscles of balance in all directions. In the third exercise, the subject described a circle in front of the body and then reversed the circle. The purpose of this exercise was to strengthen the muscles of lateral balance. Each exercise was repeated 10 to 12 times.

Pelvic tilt.- The pelvic tilt was used to strengthen muscles of the back and to counteract back pain resulting from fatigue. The subject stood with the heels, buttocks, shoulders, and head against the wall. The front of the pelvis was tilted until the small of the back was also against the wall. Initially the exercise was repeated 5 times and then was increased to 10 times.

Barbell exercise.- The barbell was used to develop body strength. The first exercise was a modified clean. It was started with the knees slightly bent, then the barbell was lifted to the thigh rest position, to the chest position, and pressed overhead. Its purpose is to develop muscles of the legs, back, and arms. Two sets of 12 repetitions each were used. The second exercise was performed by pressing the weight overhead, then lowering and raising the weight behind the neck. Its purpose was to strengthen the tricaps. Eventually, two sets of 12 repetitions each were used. The third exercise was the bench press. It was performed while lying on the back on a low bench holding the barbell against the chest with both hands. The barbell was pressed upward and then lowered and repeated at least 10 times. The purpose of this exercise was to strengthen the muscles of the chest. The fourth exercise was the front curl. This exercise was performed by grasping the barbell with knuckles up; then, from the thigh rest position, the barbell is brought up the chest. The fifth exercise was a back curl and was performed similar to the front curl but with the barbell bar being held with knuckles downward; this was repeated 10 times. The weight utilized for each exercise was determined by the individual.

Running.- Running was used for respiratory and normal physical conditioning. A normal running style was used with distance varying from 1/2 to 1 mile in 7 minutes or under.

In-Flight Exercises

The exercises described in this section were used to maintain the crew's physical condition during the flight.

Sitting.- The following exercises were done in a sitting position.

Leg push: For the leg push, the exerciser was held by both hands and the right foot was pushed against the middle of the exerciser. Next, the left foot and then both feet were pushed against the middle of the exerciser. Each action was repeated about 5 times.

Arm abduction: For the first arm abduction exercise, the exerciser was held by both hands and stretched in front of the chest about 5 times. For the second one, the exerciser was held by both hands and was stretched behind the neck with the head erect. This exercise was also repeated about 5 times.

Shoulder exercise: For the shoulder exercise, the exerciser was held by both hands and stretched behind the shoulders about 5 times.

Leg abduction: For the leg abduction exercises, the exerciser was held in the left hand and on the right foot, then the right foot was swung to the right and then to the left; this was repeated about 5 times. Next, the exerciser was held in the right hand and on the right foot, then the right foot was swung toward the midline of the body, resistance being offered with the right hand. The exercise was then performed with the left hand and left foot. This exercise was repeated with each hand and foot about 5 times.

Standing.- The following exercises were done in a standing position.

Pelvic tilt: The pelvic tilt was performed in the same manner as that described in the section "Preflight Exercises."

Side bending: For side bending, the exerciser was placed on the left foot and in the right hand and the subject bent to the right. Then the sequence was changed to the right foot and left hand. The subject repeated the exercise about 5 times.

Back extension: For the back extension exercise, the exerciser was held in both hands and the subject stood on the middle of the exerciser with both feet. Without bending his knees, he flexed from the hips and then straightened the hips and back. This procedure was repeated about 5 times.

Quarter knee bends: For quarter knee bends, the exerciser was held in both hands and the subject stood in the middle of the exerciser with both feet. Both knees were bent one-quarter and then straightened about 5 times.

Abdominal exercise: For abdominal exercise, the subject drew in the abdominal muscles and held for 6 seconds; this was repeated 5 times.

APPENDIX B

HARVARD STEP TEST PROTOCOL

This appendix describes the procedure used in the Harvard step test.

Equipment.- The following equipment was used for the test:

Platform approximately $19\frac{1}{2}$ inches high, of the nonskid type, and a top area of 2 square feet
Metronome capable of 1 beat per second
Stop watch with sweep second hand
Hand counter to record number of steps climbed

Techniques.- The techniques used in performing this test were as follows. The subject was dressed in underwear, socks, and tennis shoes. The subject stepped upon the platform during the 1st second, stepped down during the 2d second, stepped up during the 3d second, and continued in this manner for 5 minutes. The subject was advised to crouch forward as low as he chose when stepping up, thus negating the necessity of coming to a full upright position on the step. The subject was further advised that if he was unable to keep up with the metronome, he was to continue as near as possible to a metronome pace. If the subject stumbled or fell, he was encouraged to continue the test if he was uninjured. After these instructions, the metronome was started and as soon as the subject began his first step, the stop watch was started. During the test no encouragement or other directions were given. At the end of 5 minutes the subject immediately sat down. The physician then recorded the pulse during three time periods (the end of the test being considered time zero): from 1 to to $1\frac{1}{2}$ minutes, from 2 to $2\frac{1}{2}$ minutes, and from 4 to $4\frac{1}{2}$ minutes. All pulses were recorded by precordial auscultation; the recording of the pulses ended the tests.

Scoring.- For scoring purposes, it was assumed that a high post-exercise pulse reflected poor physical fitness and a low number of step-ups reflected poor subject participation. The total step-up value S was divided by the total pulse value P multiplied by 150 to give the final Harvard step test score as shown by the following equation:

$$\text{Score} = \frac{S}{P} \times 150$$

All subjects should be able to perform for 5 minutes. The average step score should be 52.8. An acceptable range is from 45 to 100.

REFERENCES

1. Markson, E., Bryant, J., and Bergsten, F.: Simulation of Manned Lunar Landing. [Preprint] 2482-62, American Rocket Soc., July 1962.

2. Bryant, J. P., and Frank, M. P.: Supercircular Re-Entry Guidance for a Fixed L/D Vehicle Employing a Skip for Extreme Ranges. [Preprint] 2489-62, American Rocket Soc., July 1962.

3. Brissenden, Roy F., Burton, Bert B., Foudriat, Edwin C., and Whitten, James B.: Analog Simulation of a Pilot-Controlled Rendezvous. NASA TN D-747, 1961.

4. Queijo, M. J., Miller, G. Kimball, Jr., and Fletcher, Herman S.: Fixed-Base-Simulator Study of the Ability of a Pilot To Perform Soft Lunar Landings. NASA TN D-1484, 1962.

5. Grodsky, Milton A., and Bryant, John P.: Crew Performance During Simulated Lunar Missions. ER 12693 (Contract NAS1-1861), Martin Marietta Corp., Aug. 1962.

6. Grodsky, Milton A.: An Investigation of Crew Performance During a Simulated Seven-Day Lunar Orbit Mission - Part I. Performance Results. RM-121, Martin Marietta Corp., Jan. 1963.

7. Algranti, Joseph S., Mallick, Donald L., and Hatch, Howard G., Jr.: Crew Performance on a Lunar-Mission Simulation. A report on the Research and Technological Problems of Manned Rotating Spacecraft. NASA TN D-1504, 1962, pp. 135-146.

8. Mallick, Donald L., and Ream, Harold E.: Crew Performance and Personal Observations on a Lunar Mission Simulation. Paper No. 63-18, Inst. Aerospace Sci., Jan. 1963.

TABLE I.- TOTAL NUMBER OF PREFLIGHT PRACTICE AND BASE-LINE

FLIGHT-CONTROL RUNS (FROM REF. 5)

	Preflight I						Preflight II						Preflight III					
	Main vehicle			LOR vehicle			Main vehicle			LOR vehicle			Main vehicle			LOR vehicle		
Phase \ Pilot	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Launch from earth	5	7	13				3							2				
Translunar insertion	3	2	10				5							2				
Translunar midcourse	5	4	1				4	4						3	3			
Lunar orbit insertion	4	2	2				4							2				
Lunar deorbit							4	4										
Lunar landing braking	23	7	18	15	21	21	4	6		3	4		3	3	3	6	3	5
Lunar launch and orbit	9	4	5	2	6	2		1		3	4		3	3	3	2	2	2
Rendezvous				11	10	4					1					3	2	3
Transearth insertion														2				
Transearth midcourse																		
Reentry													6	8	12			
Lunar abort	2	3	2	2	3	6	2	3		2	2		1				1	1

TABLE II.- VARIABLES USED FOR EVALUATION OF

CREW PERFORMANCE (FROM REF. 5)

Phase	Variables
Launch from earth	θ, ψ, and ϕ $\int \sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\, dt$
Translunar insertion	ΔV_e and $\int \sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\, dt$
Translunar midcourse corrections	ΔV_e
Lunar orbit insertion	ΔV_e and $\int \sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\, dt$
Lunar deorbit	ΔV_e and $\int \sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\, dt$
Lunar landing braking	$\dot{x}_f$, $\dot{h}_f$, $\dot{\psi}_f$, $\dot{\theta}_f$, $\dot{\phi}_f$, $\theta_{e,f}$, $\psi_{e,f}$, $\phi_{e,f}$, V_f, and fuel
Lunar launch and orbit	ΔV_e and $\int \sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\, dt$
Rendezvous	x_f, $\dot{x}_f$, y_f, $\dot{y}_f$, z_f, $\dot{z}_f$, and fuel
Transearth insertion	ΔV_e and $\int \sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\, dt$
Transearth midcourse	ΔV_e
Reentry	$\int \sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\, dt$, $\dot{h}_e$, and $\int V h_e\, dt$

TABLE III.- PREFLIGHT BASE-LINE AND FLIGHT AVERAGE

VELOCITY ERROR COMPARISONS

Phase	Pilot	Preflight ΔV_e	Flight ΔV_e
Translunar insertion	B	5.5 (2 runs)	0 (1 run)
Translunar midcourse corrections	A	0.45 (2 runs)	0.24 (3 runs)
	B	.24 (3 runs)	1.03 (1 run)
	C	.21 (3 runs)	.19 (1 run)
Lunar orbit insertion	A	15.25 (4 runs)	7 (1 run)
	B	3 (2 runs)	2 (1 run)
Lunar deorbit	A	0.93 (4 runs)	1.2 (2 runs)
	B	1.5 (4 runs)	.5 (2 runs)
Lunar launch and orbit	A	10.6 (5 runs)	0 (2 runs)
	B	6.2 (5 runs)	0 (2 runs)
	C	1.8 (5 runs)	7 (2 runs)

TABLE IV.- LUNAR LANDING TERMINAL CONDITIONS

(a) Pilot A

Trial	$\dot{h}_f$	$\dot{\psi}_f$	$\dot{\theta}_f$	$\dot{\phi}_f$	$\psi_{e,f}$	$\theta_{e,f}$	$\phi_{e,f}$	V_f	Percent fuel
LOR landings									
Preflight I	3.8	0.89	------	------	49.0	-1.38	48.0	------	-----
	3.73	-.32	------	------	-.3	67	-57.2	------	-----
	20.87	1.63	-5.39	-0.066	-34.2	18.57	-3.08	130.3	-----
	15.53	.053	-1.3	.411	3.87	.75	-1.95	46.1	-----
	19.0	.296	2.14	-.46	5.68	-2.28	-.12	41.9	-----
	70.0	.169	-4.85	-.36	10.3	63.1	-1.39	7.67	-----
	19.27	.011	.60	.10	1.0	58.9	-1.1	64.6	-----
	11.47	.127	-3.02	.014	5.09	-7.2	.657	22.8	-----
Flight I	ABORT								
Preflight II	NONE								
Flight II	5.50	-0.34	-1.94	0.07	-4.3	-2.6	-0.55	7.93	102.1
Preflight III	10.53	-4.04	1.88	0.28	-2.0	12.6	1.28	115.6	96.6
	7.93	1.39	-2.78	.078	.75	1.67	1.13	-7.93	94.9
	22.10	.37	.262	.155	4.67	1.44	.398	15.3	99.0
	32.30	.50	5.53	1.06	2.16	2.93	1.78	31.9	96.1
	14.69	-.254	-1.92	-.262	-7.87	3.6	-1.8	16.2	86.9
	7.4	-.14	.533	-.322	-.84	3.42	-1.21	8.67	84.5
Flight III	8.35	0.064	-0.526	0.837	-3.44	2.66	-0.472	11.8	99.1
Direct landings									
Preflight I	40.47	-0.29	1.05	-0.719	-5.55	29.05	-0.234	50.13	88.1
	8.13	-.168	-.132	.882	-4.68	1.06	1.37	14.07	102.6
	6.73	.543	.849	-.458	-2.76	-.182	.533	11.53	108.1
	5.93	.438	.157	-.35	3.22	-2.26	-2.46	10.20	97.9
	3.93	-.044	.989	-.267	.628	-1.49	-1.26	8.0	97.6
	5.6	.071	2.01	-.61	.40	-1.93	2.06	9.67	93.7
	31.06	-.96	4.63	-1.57	-6.21	-14.50	1.37	37.6	87.9
	6.2	.16	.534	-.085	-2.76	-2.33	-.824	10.8	97.6
Flight I	5.53	0.232	0.731	0.503	-0.551	-2.0	1.70	5.93	95.6
Preflight II	8.14	0.68	3.87	0.463	1.04	-19.05	-7.47	137.54	95.1
	57.27	-.93	5.10	1.61	2.69	-22.0	4.83	95.27	94.1
	.6	-.13	.365	-.089	.279	.756	-.189	-2.33	104.6
	25.67	-.02	.327	-.693	.956	-2.2	1.21	43.27	94.1
Flight II	1.33	0.12	1.16	0	0.745	-1.8	0.434	2.87	124.1
Preflight III	4.07	0.241	-2.39	0.050	0.038	5.15	1.52	7.00	97.8
	3.73	.043	.236	.013	.203	-.38	.045	6.67	91.7
	6.66	.442	-.248	-.183	.142	-1.7	-1.24	11.27	90.6
Flight III	4.20	0.012	0.067	0.042	0.24	2.32	0.063	7.4	-----

TABLE IV.- LUNAR LANDING TERMINAL CONDITIONS - Continued

(b) Pilot B

Trial	$\dot{h}_f$	$\dot{\psi}_f$	$\dot{\theta}_f$	$\dot{\phi}_f$	$\psi_{e,f}$	$\theta_{e,f}$	$\phi_{e,f}$	V_f	Percent fuel
LOR landings									
Preflight I	0	-0.65	------	------	-2.92	0.68	3.6	1704	-----
	11.67	-.24	------	------	-2.93	-1.64	-.92	1543	-----
	3.47	-.24	------	------	.5	1.94	2.08	4.6	-----
	7.67	-.30	------	------	-6.82	2.28	.56	9.8	-----
	2.4	-.82	------	------	2.46	4.18	-1.68	2.47	-----
	20	.13	1.35	0.05	4.64	7.29	-3.31	42.6	-----
	3.66	.24	-.41	-.48	16.7	1.75	-.75	7.3	-----
	15.33	.146	-1.85	.412	9.58	-2.03	-1.22	23.3	-----
	26.3	.387	-1.32	-.056	7.15	-12.55	-3.65	60.9	-----
	21.46	.287	2.89	.079	.09	68.54	-3.37	36.73	95.3
	5.8	-2.38	1.09	-.041	4.89	-2.29	-.697	9.93	101.4
	17.4	-.129	.568	1.07	.426	60.0	-1.5	21.00	101.4
Flight I	7.8	0.02	-0.57	-0.16	-2.22	2.36	-1.71	-15.07	94.1
Preflight II	NONE								
Flight II	7.13	0.46	1.27	0.01	-0.01	4.21	-2.02	12.07	102.8
Preflight III	-176.2	0.276	6.81	-0.88	1.78	22.3	4.10	199.3	94.9
	7.6	.091	.858	.160	.77	3.9	-1.06	12.9	89.7
	8.0	-.08	.447	.40	-1.58	2.61	-1.36	13.4	86.4
Flight III	7.06	0.40	0.207	-0.162	-1.34	-1.03	-3.14	58.0	91.3
Direct landings									
Preflight I	8.47	0.048	-1.31	0.813	-3.02	-0.58	-0.56	14.73	98.1
	6.13	-.234	.856	-.068	-2.86	-1.55	-1.09	10.53	98.1
	5.73	.019	-.264	-.615	.668	1.56	5.93	9.93	95.6
Flight I	6.53	-0.25	-0.27	0.66	0.464	-4.83	-3.55	11.47	100.4
Preflight II	4.6	0.340	-1.75	-0.503	-0.718	5.76	-0.538	7.93	86.9
	7.6	-.24	-1.74	-.291	.047	-3.5	2.04	13.27	104.1
	4.53	-.077	-1.87	-.015	.047	-1.8	.844	8.07	123.9
Flight II	ABORT								
Preflight III	5.93	-0.038	0.581	-0.038	-1.32	-0.112	9.93	9.93	88.6
	5.93	.035	.393	.026	.342	-1.50	-.741	10.07	89.4
	4.80	.287	-.247	.019	.32	.54	-.243	8.33	90.0
Flight III	ABORT								

TABLE IV.- LUNAR LANDING TERMINAL CONDITIONS - Concluded

(c) Pilot C

Trial	$\dot{h}_f$	$\dot{\psi}_f$	$\dot{\theta}_f$	$\dot{\phi}_f$	$\psi_{e,f}$	$\theta_{e,f}$	$\phi_{e,f}$	V_f	Percent fuel
LOR landings									
Preflight I	18.1	-0.24	------	------	-13.7	67	-3.13	-------	-----
	133.3	-.24	------	------	-6.68	55.8	1.15	1140	-----
	13.06	-.24	------	------	-6.0	50.4	-5.06	295.3	-----
	9.07	-.24	------	------	-5.17	49.4	4.16	-------	-----
	.93	.529	2.07	-0.06	18.38	8.35	-.91	1.73	-----
	3.4	.11	-.14	-.14	2.78	64.6	-2.97	44.67	-----
	13.26	-1.84	.33	-.067	20.93	-1.3	-1.47	51.67	-----
	16.8	.065	.789	.06	-6.52	-3.17	-2.36	21.67	-----
	70.0	4.87	.716	-.343	-53.3	15.3	-1.06	83.6	-----
	51.13	.290	.992	.075	7.70	19.2	-2.22	51.5	92.1
	14.4	-.283	-2.27	-.328	2.70	.277	-2.24	15.73	103
	57.47	-1.87	.837	.148	11.8	2.2	-1.44	57.6	98.2
	10.53	.467	-.312	.145	-5.36	55.31	-.69	11.0	96.1
	12.4	.048	-1.65	-6.28	5.27	4.2	3.46	22.1	101.4
Flight I	15.73	-1.02	-0.081	0.248	10.03	6.08	-0.659	20.2	103
Preflight II					NONE				
Flight II					NONE				
Preflight III	13.86	0.081	0.021	0.025	0.203	3.47	1.07	19.67	85.0
	19.60	-.090	.381	-.045	-1.10	2.80	-.705	32.20	81.7
	4.60	-.024	.094	.057	.636	.67	-.31	8.13	81.8
	16.93	-.236	4.77	-.423	-------	21.13	------	-17.26	90.0
	2.33	1.043	.993	.016	-------	24.52	------	48.93	89.5
	19.2	1.58	-2.04	.082	9.3	12.3	.027	19.55	86.8
	4.0	.065	-.53	-.397	-5.7	3.84	-2.23	6.6	90.8
Flight III	15.95	-0.392	-5.39	0.298	-0.762	12.05	-1.61	16.3	85.1
Direct landings									
Preflight I	6.0	-0.25	0.915	-0.049	-77.35	0.875	-0.95	10.4	94.6
	2.27	-.25	-1.37	-.012	-78.7	-4.09	2.44	4.13	95.1
	13.8	-.25	.068	-.578	-6.8	2.0	-2.26	23.73	93.6
	4.07	-.25	-.539	-.242	-.88	-1.26	2.13	7.07	95.9
	3.07	.052	-2.69	-.349	1.08	2.0	6.38	5.53	93.4
Flight I					ABORT				
Preflight II					NONE				
Flight II					NONE				
Preflight III					NONE				
Flight III	3.27	0.077	-2.25	-0.008	0.864	-0.252	-0.944	5.93	82.0

TABLE V.- AVERAGE TERMINAL CONDITIONS FOR RENDEZVOUS

Variable	Pilot A		Pilot B		Pilot C	
	Base line (3 runs)	Flight (3 runs)	Base line (6 runs)	Flight (3 runs)	Base line (4 runs)	Flight (1 run)
Range, ft	5.3	4.6	5.8	5.9	10.8	3.6
Range rate, ft/sec	1.5	1.8	2.3	1.9	2.1	1.5
Total impulse, lb-sec	123,691	85,106	145,014	117,198	124,962	96,077
Total time, min	13.49	17.19	16.63	15.18	19.77	21.45

TABLE VI.- REENTRY PERFORMANCE

Run	Pilot	$\int\sqrt{\theta_e^2 + \psi_e^2 + \phi_e^2}\,dt$	$\int Vh_e\,dt$	$\dot{h}_e$
Base line	A	10,411	40.7	1.4
	B	6,657	24.8	
	C	9,551	37.0	
Flight	A	8,862	43.5	0.5
	B	10,330	46.5	.7
	C	5,477	7.5	.15

TABLE VII.- FLIGHT II PHYSICAL CONDITIONING EVALUATION (FROM REF. 5)

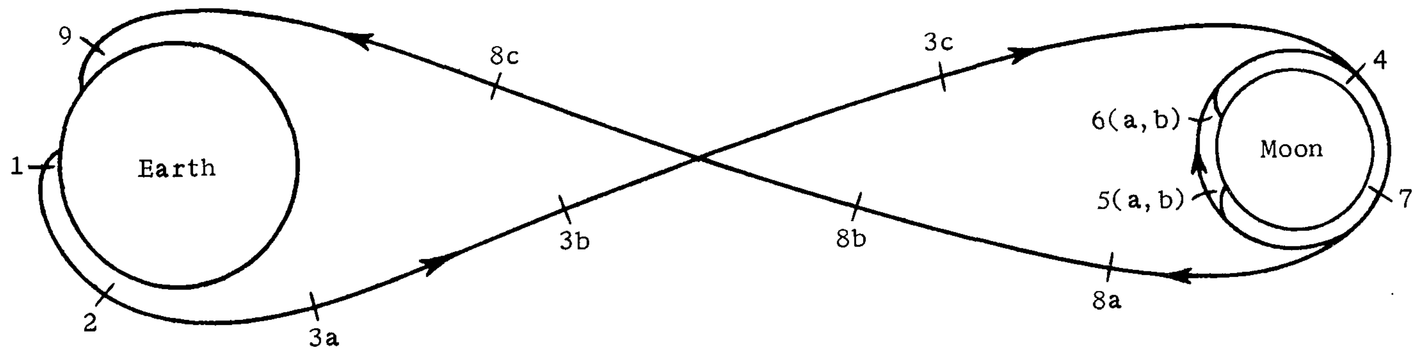
Pilot	Jumping jacks	Jump rope (both feet)	Jump rope (one foot)	Push-up	Sit-up	Weights: 50 lb press	Weights: 50 lb curl
(a) Base line							
A	No.: 101 Time: 81 sec Rate: 1.25	No.: 100 Time: 62 sec Rate: 1.61	No.: 100 Time: 46 sec Rate: 2.17	No.: 28 Time: 41 sec Rate: 0.683	No.: 40 Time: 93 sec Rate: 0.432	No.: 15 Time: 67 sec Rate: 0.224	No.: 20 Time: 45 sec Rate: 0.444
B	No.: 101 Time: 102 sec Rate: 0.990	No.: 80 Time: 58 sec Rate: 1.38	No.: 60 Time: 34 sec Rate: 1.76	No.: 35 Time: 45 sec Rate: 0.756	No.: 50 Time: 145 sec Rate: 0.345	No.: 15 Time: 107 sec Rate: 0.140	No.: 15 Time: 65 sec Rate: 0.231
(b) Postflight							
A	No.: 101 Time: 92 sec Rate: 1.09	No.: 100 Time: 34 sec Rate: 2.56	No.: 100 Time: 44 sec Rate: 2.27	No.: 30 Time: 40 sec Rate: 0.750	No.: 40 Time: 91 sec Rate: 0.439	No.: 15 Time: 65 sec Rate: 0.231	No.: 20 Time: 42 sec Rate: 0.476
B	No.: 101 Time: 98 sec Rate: 1.03	No.: 80 Time: 47 sec Rate: 1.70	No.: 60 Time: 29 sec Rate: 2.07	No.: 35 Time: 41 sec Rate: 0.854	No.: 50 Time: 132 sec Rate: 0.379	No.: 15 Time: 86 sec Rate: 0.174	No.: 15 Time: 35 sec Rate: 0.428

TABLE VIII.- HARVARD STEP TEST (FROM REF. 5)

Pilot	Initial examination		Preflight III		Postflight III	
	Trips	Score	Trips	Score	Trips	Score
A	155	57	152	64	151	58
B	151	64	150	61	155	60
C	154	61	152	56	151	54

TABLE IX.- SYSTOLIC BLOOD PRESSURE DURING FLIGHT III (FROM REF. 5)

Mission time, hr	Systolic pressure		
	Pilot A	Pilot B	Pilot C
-2.0 preflight	105	134	110
5.0	104	128	108
12.0	108		108
16.0		126	
20.5	112	110	
24.0			118
30.0		130	
33.0			104
34.0	122		
36.0	108	118	
40.0			102
43.0		126	
48.0	102	116	
52.0		108	112
55.0	102		112
56.0		114	
64.0	118	120	
66.0			94
76.0	110	126	108
82.0	112		103
84.0		125	
89.0	105		98
92.0		120	
97.0	110	112	
99.0		122	
105.0	108		105
107.0		122	
113.0	100		103
115.0		118	
122.0	120	115	
123.0			115
131.0	98	132	92
139.0	102		112
146.0			107
148.0	115	118	
155.0			108
156.0		128	
163.0	110	162	108
165.5 postflight	110	135	110



1 Launch from earth
2 Translunar insertion
3 (a,b,c) Translunar midcourse corrections
4 Lunar orbit insertion
5 Lunar deorbit and landing
  (a) Direct
  (b) LOR
6 Lunar launch and orbit
  (a) Direct
  (b) LOR rendezvous
7 Transearth insertion
8 (a,b,c) Transearth midcourse corrections
9 Reentry

Figure 1.- Mission profile.

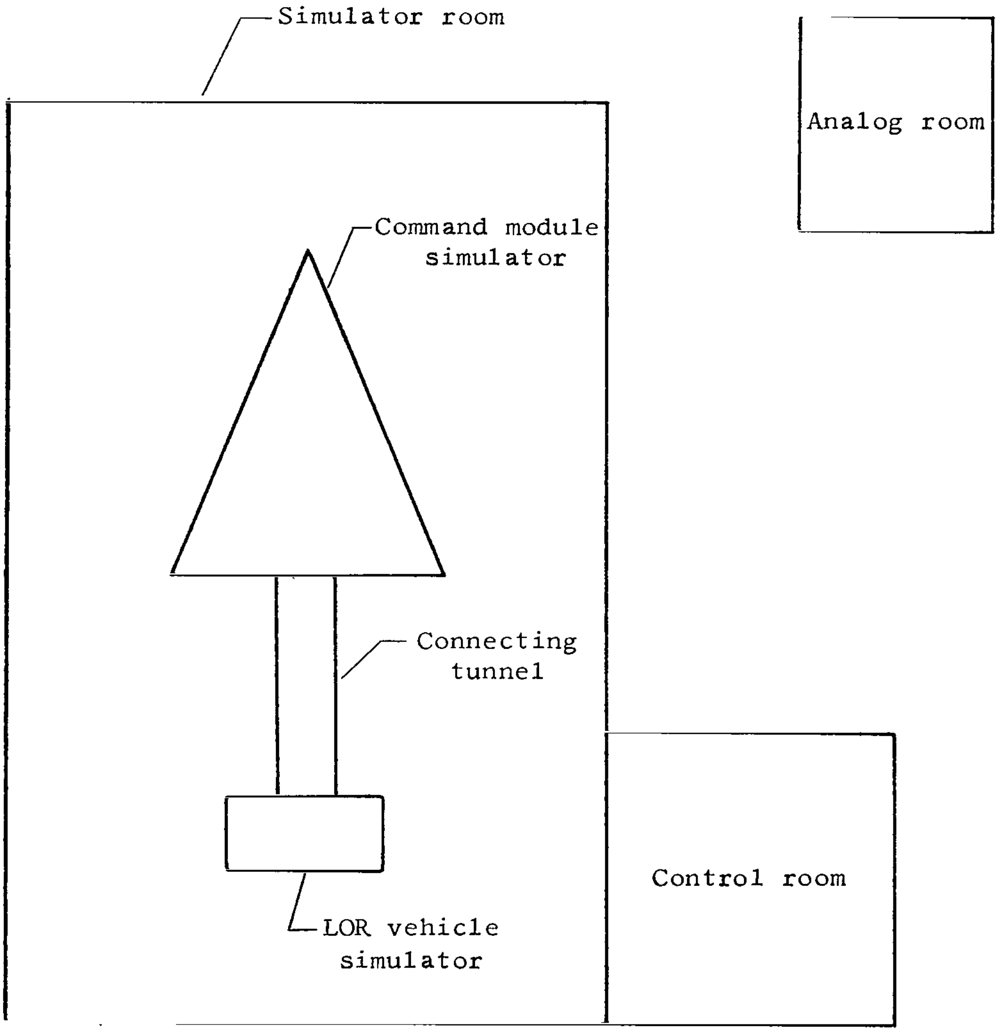


Figure 2.- Plan view of the simulation facility.

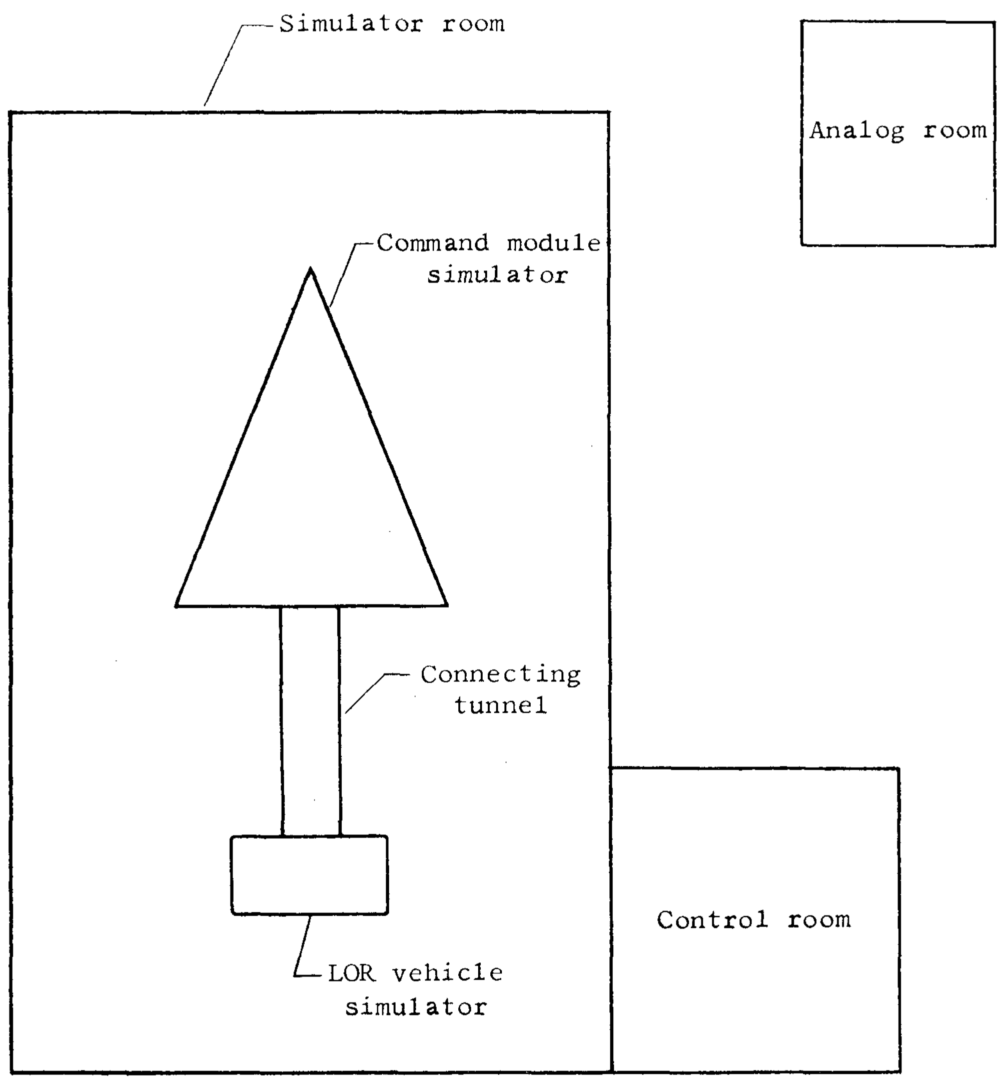


Figure 2.- Plan view of the simulation facility.

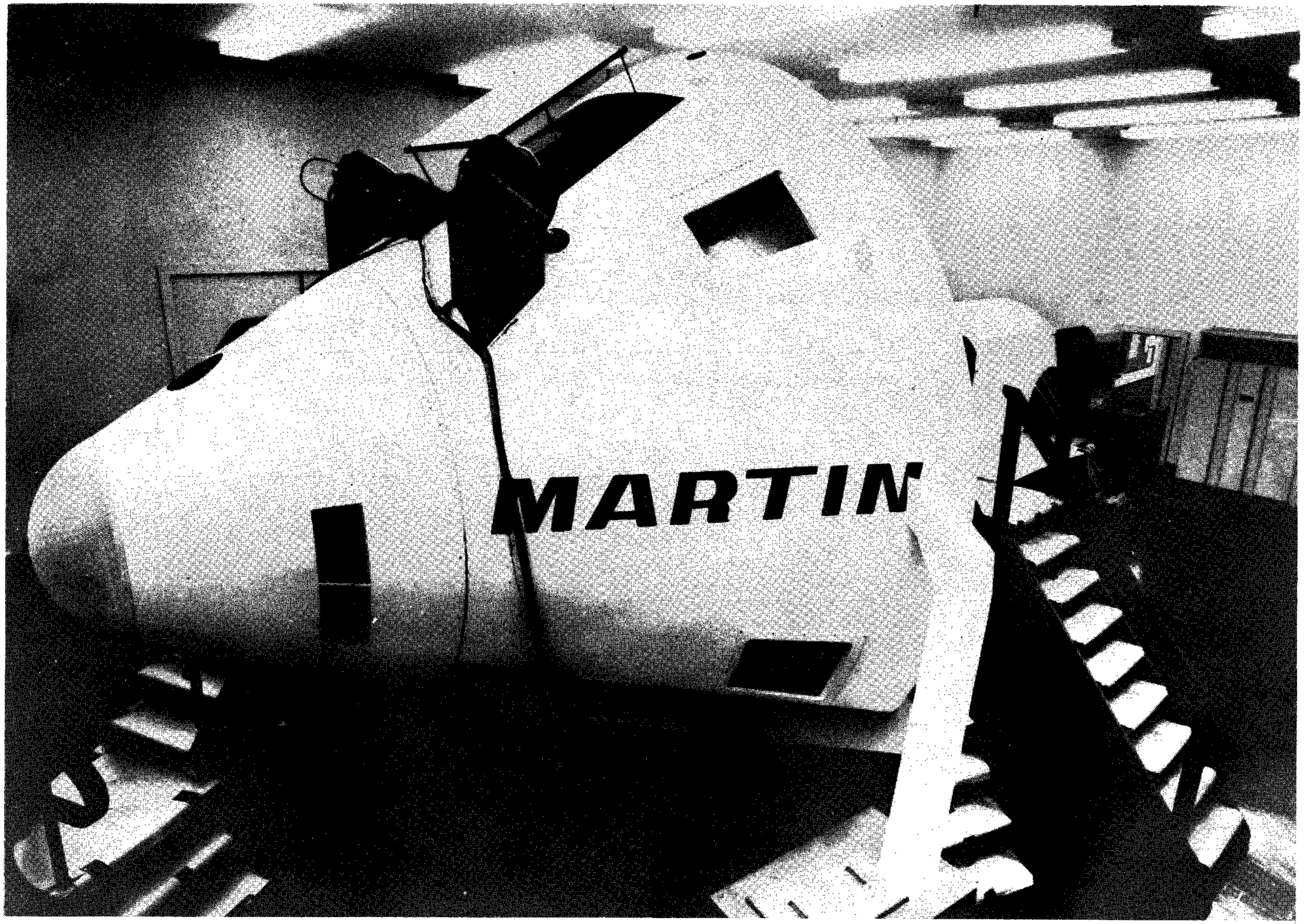


Figure 3.- External view of command module simulator. L-62-1022

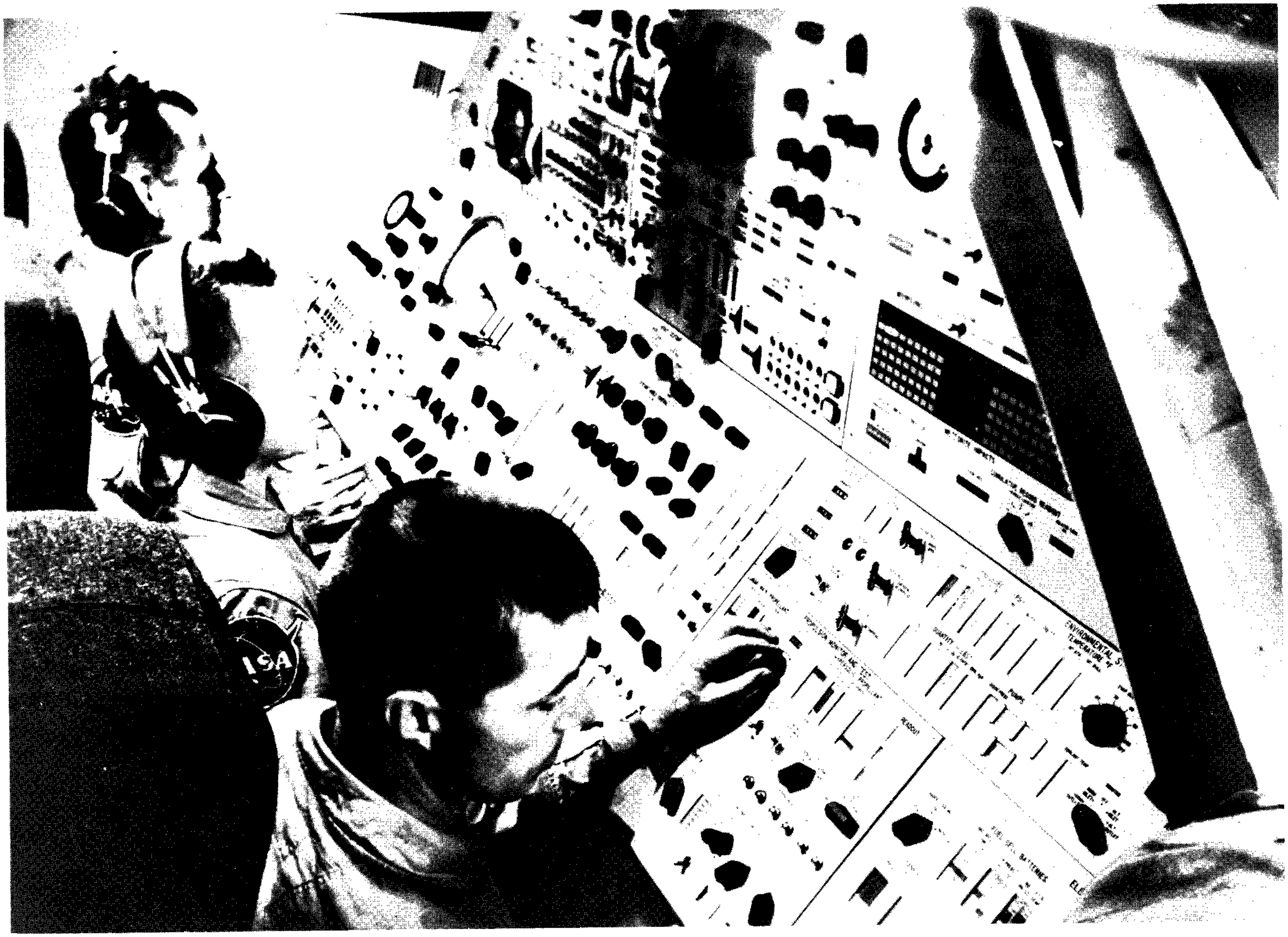


Figure 4.- Crew on station at the control and display panel. L-62-1023

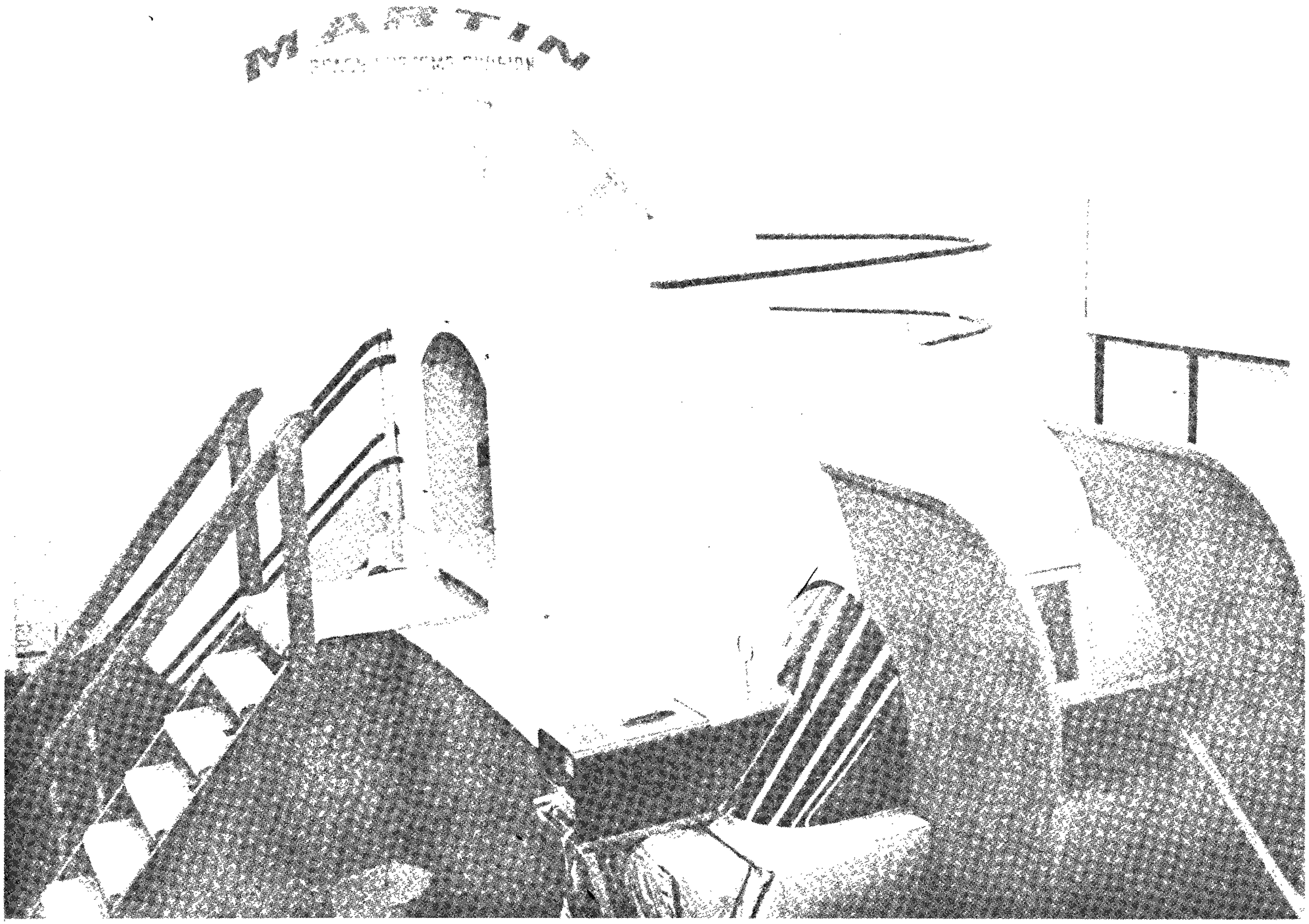
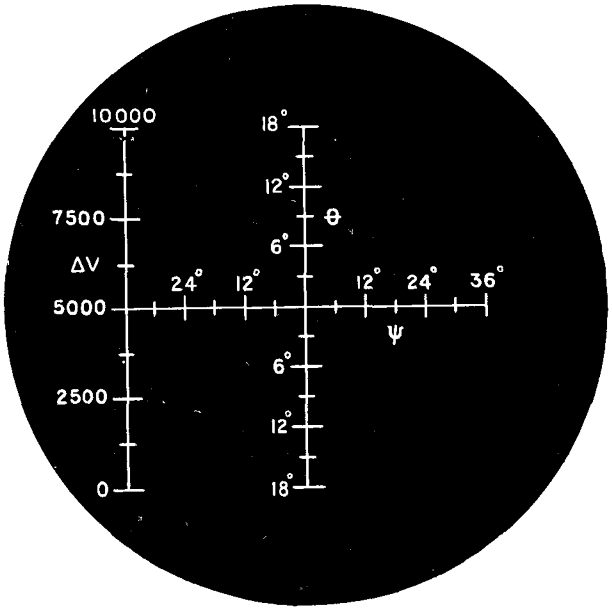
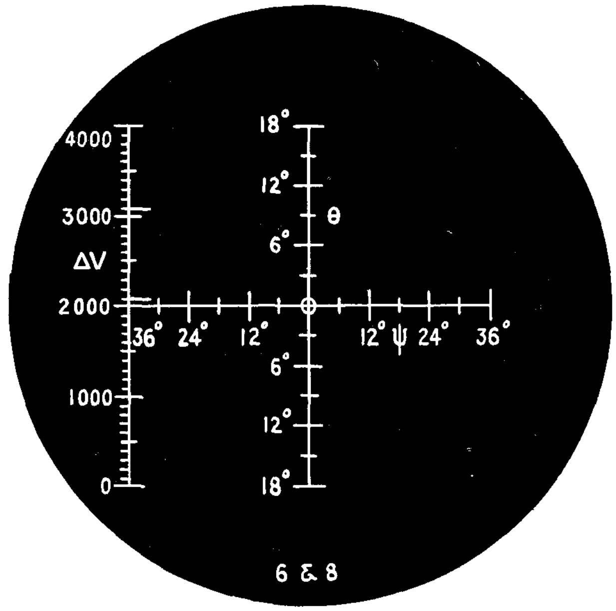


Figure 5.- View of the LOR vehicle simulator and connecting tunnel. (From ref. 5.)

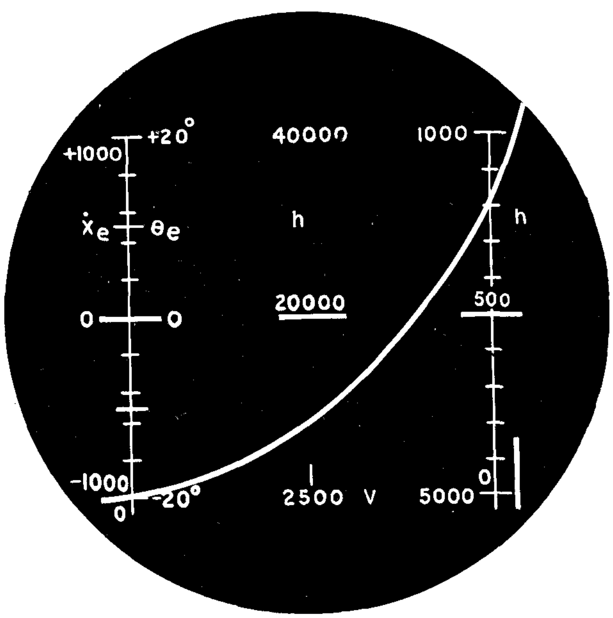
L-64-3034



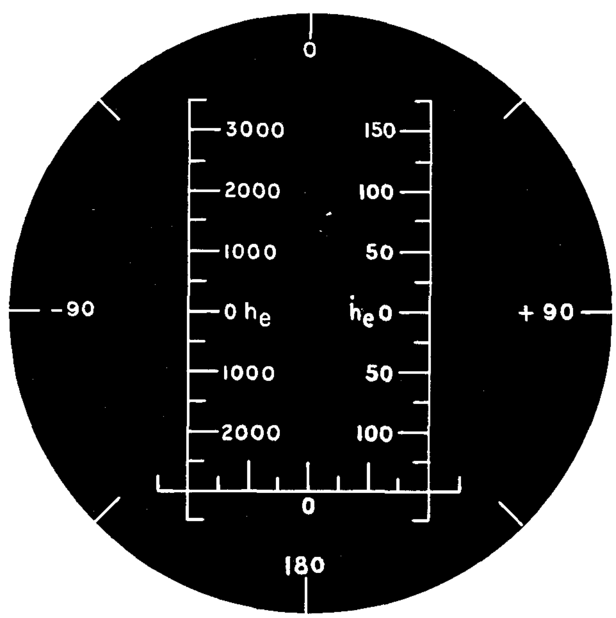
(a) Translunar insertion.



(b) Lunar orbit insertion.



(c) Lunar landing.



(d) Reentry.

Figure 6.- CRT displays. (From ref. 5.)

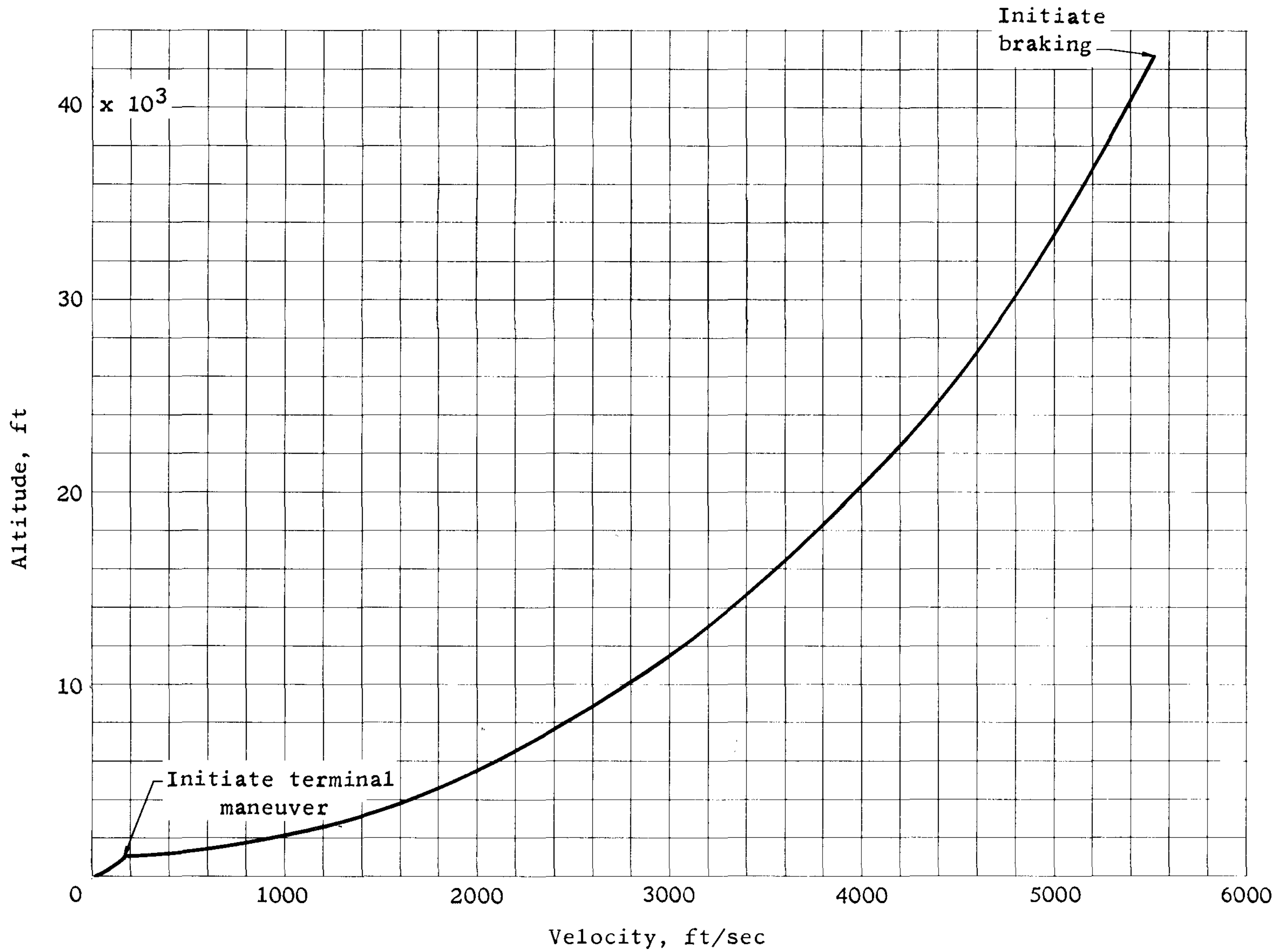


Figure 7.- Lunar landing terminal braking nominal altitude-velocity curve. (From ref. 5.)

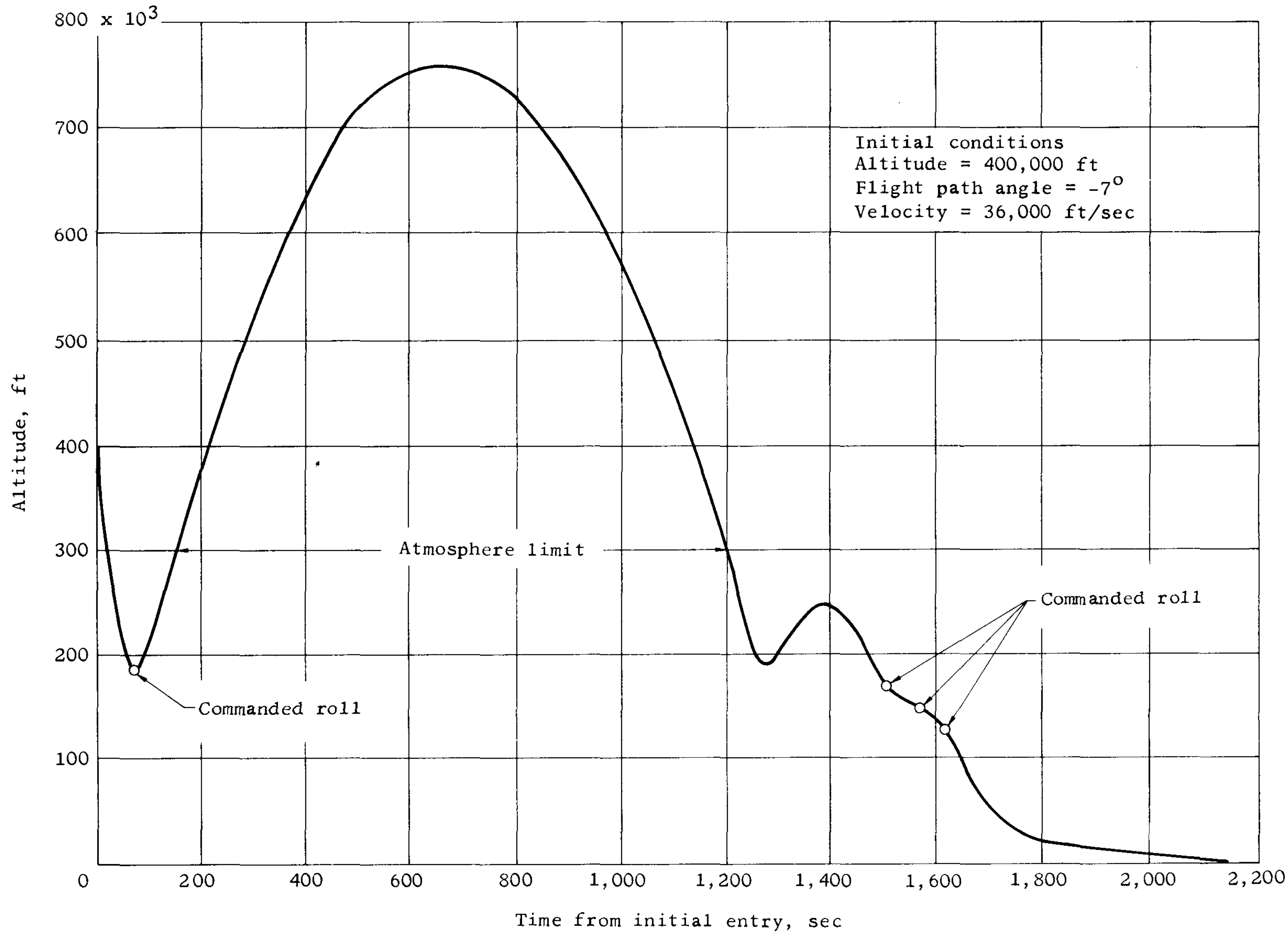


Figure 8.- Reentry trajectory. (From ref. 5.)

Figure 9.- Trisextant. L-64-3035

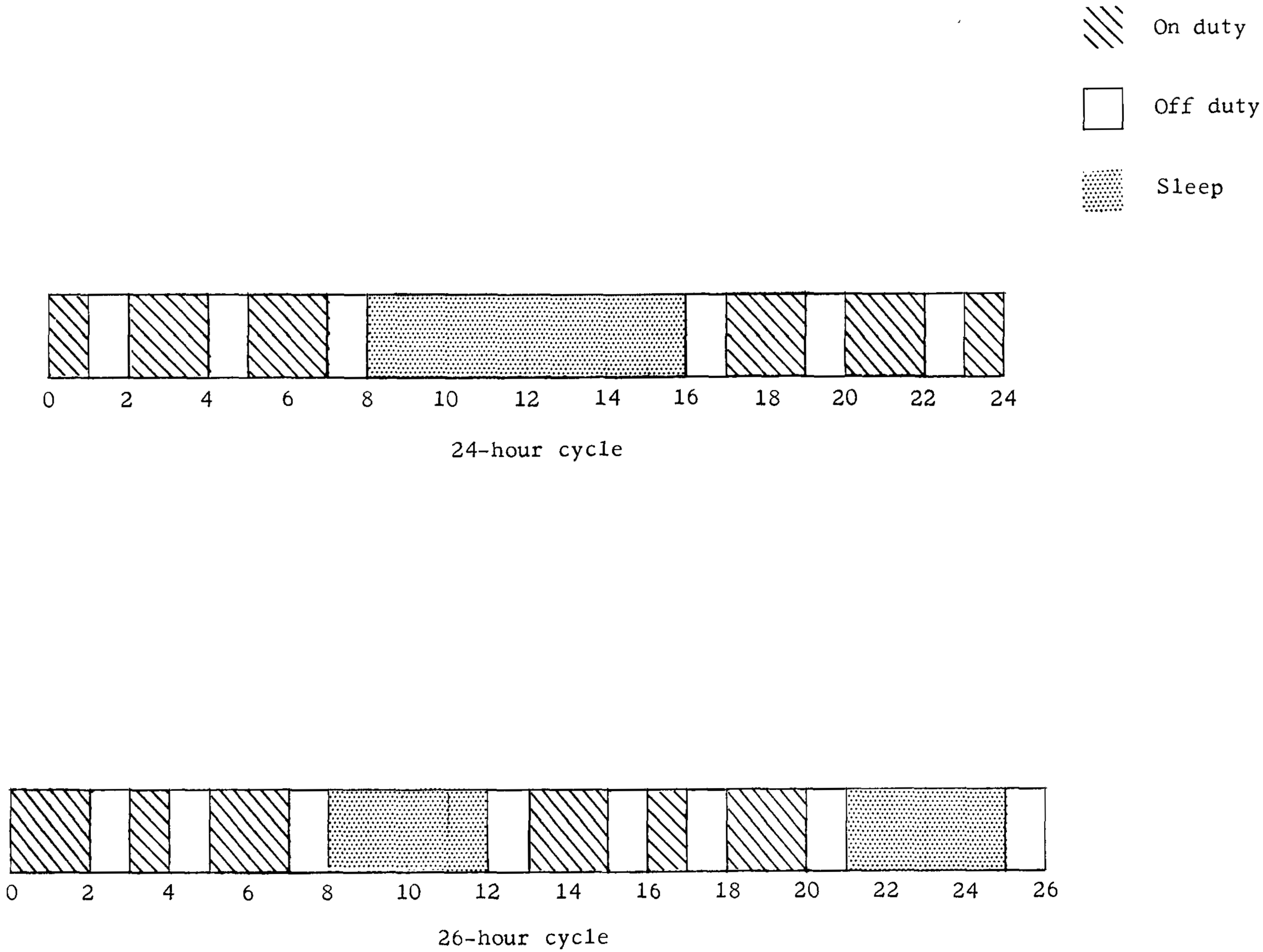


Figure 10.- Duty cycles.

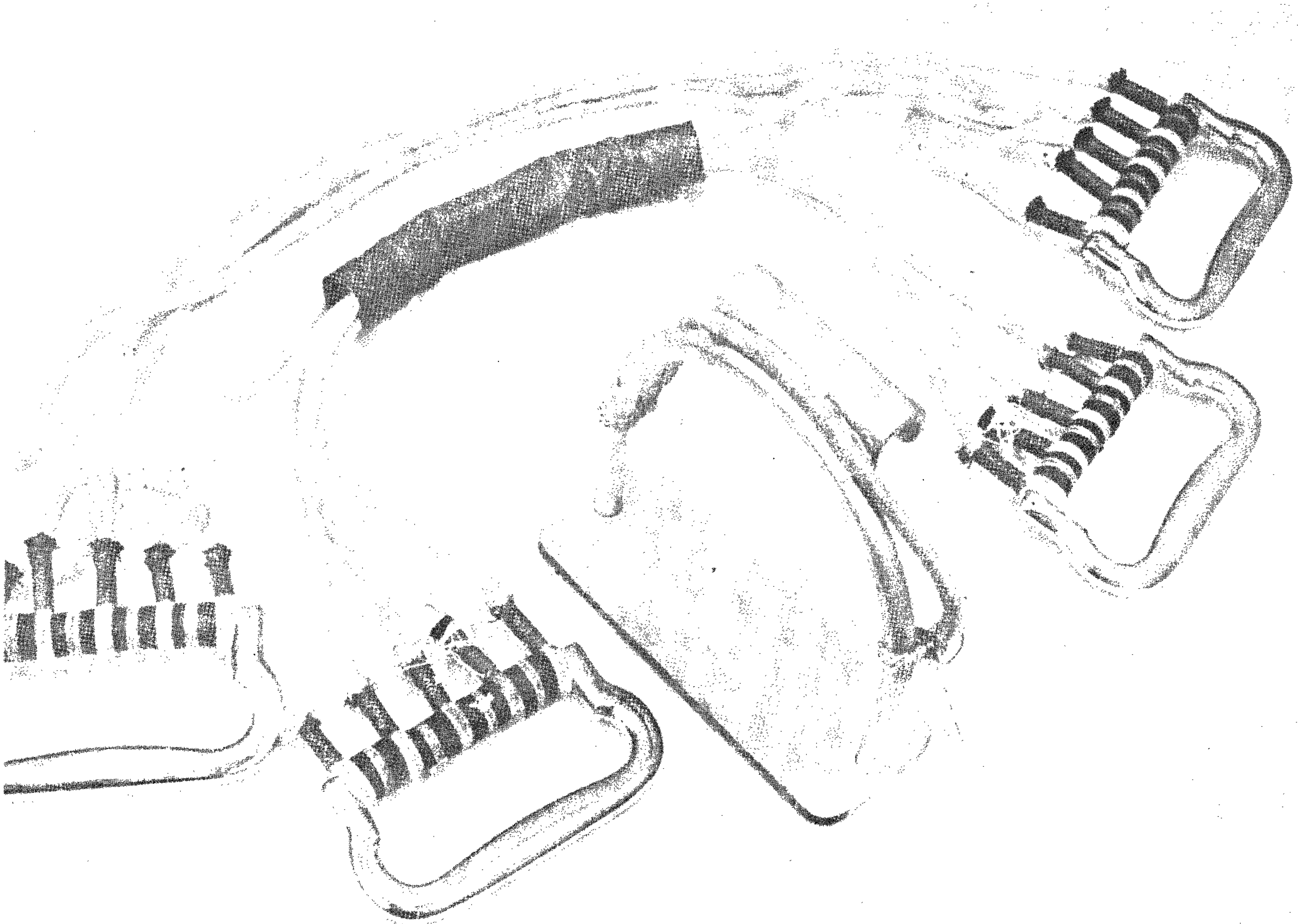


Figure 11.- In-flight exercise device. (From ref. 5.) L-64-3036

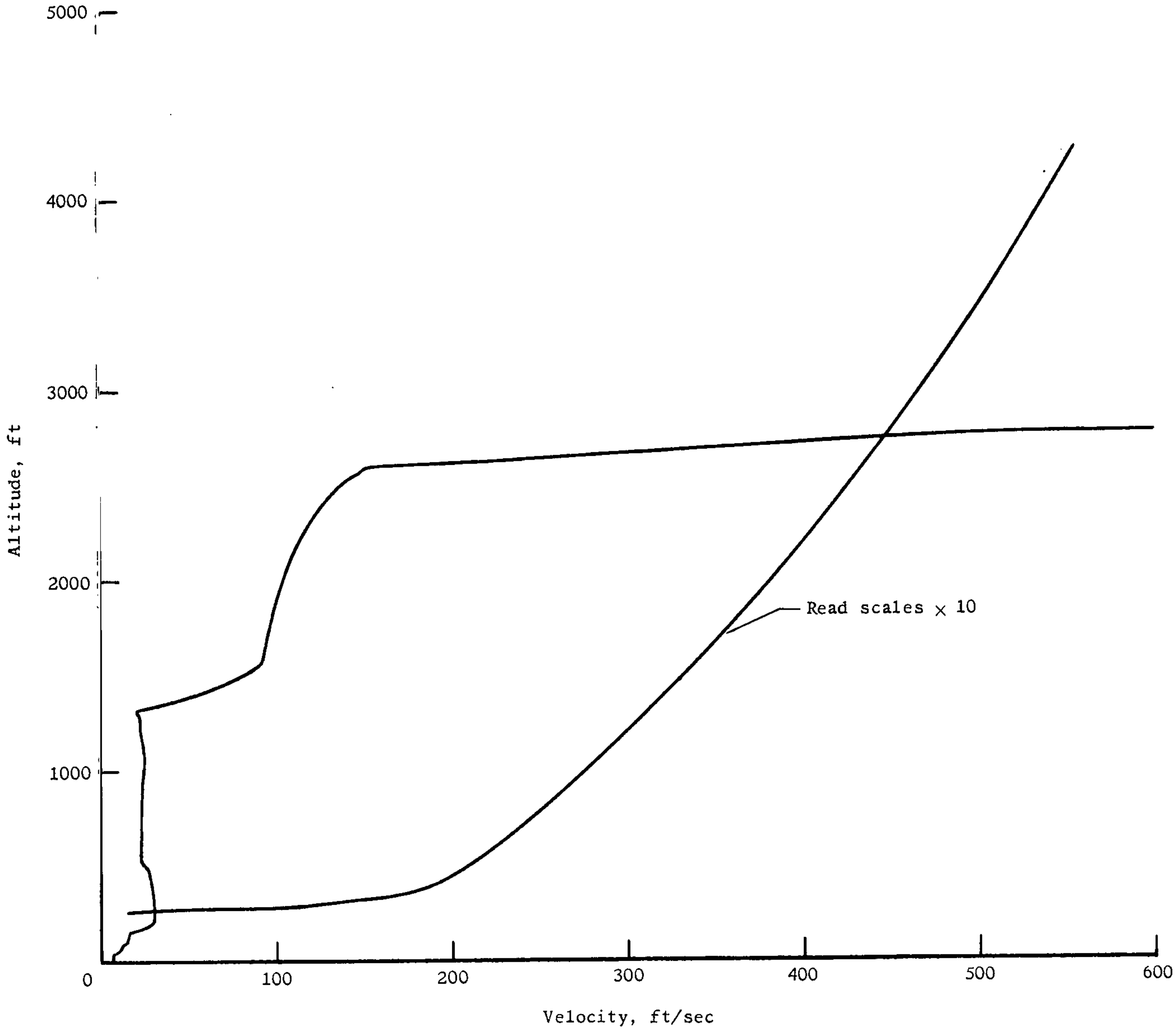


Figure 12.- Flight III direct landing. Pilot C.

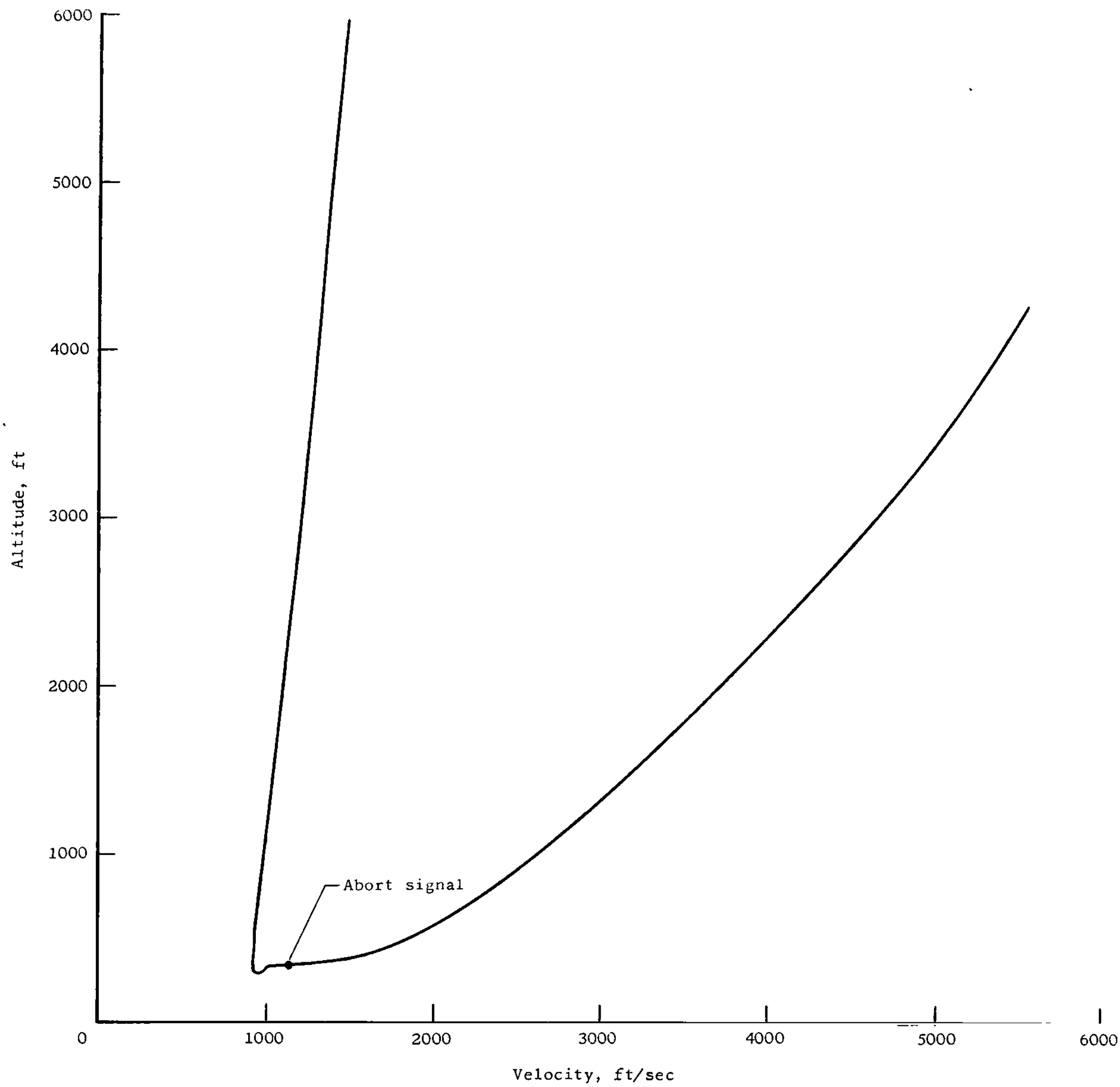


Figure 13.- Flight III aborted direct landing. Pilot B.

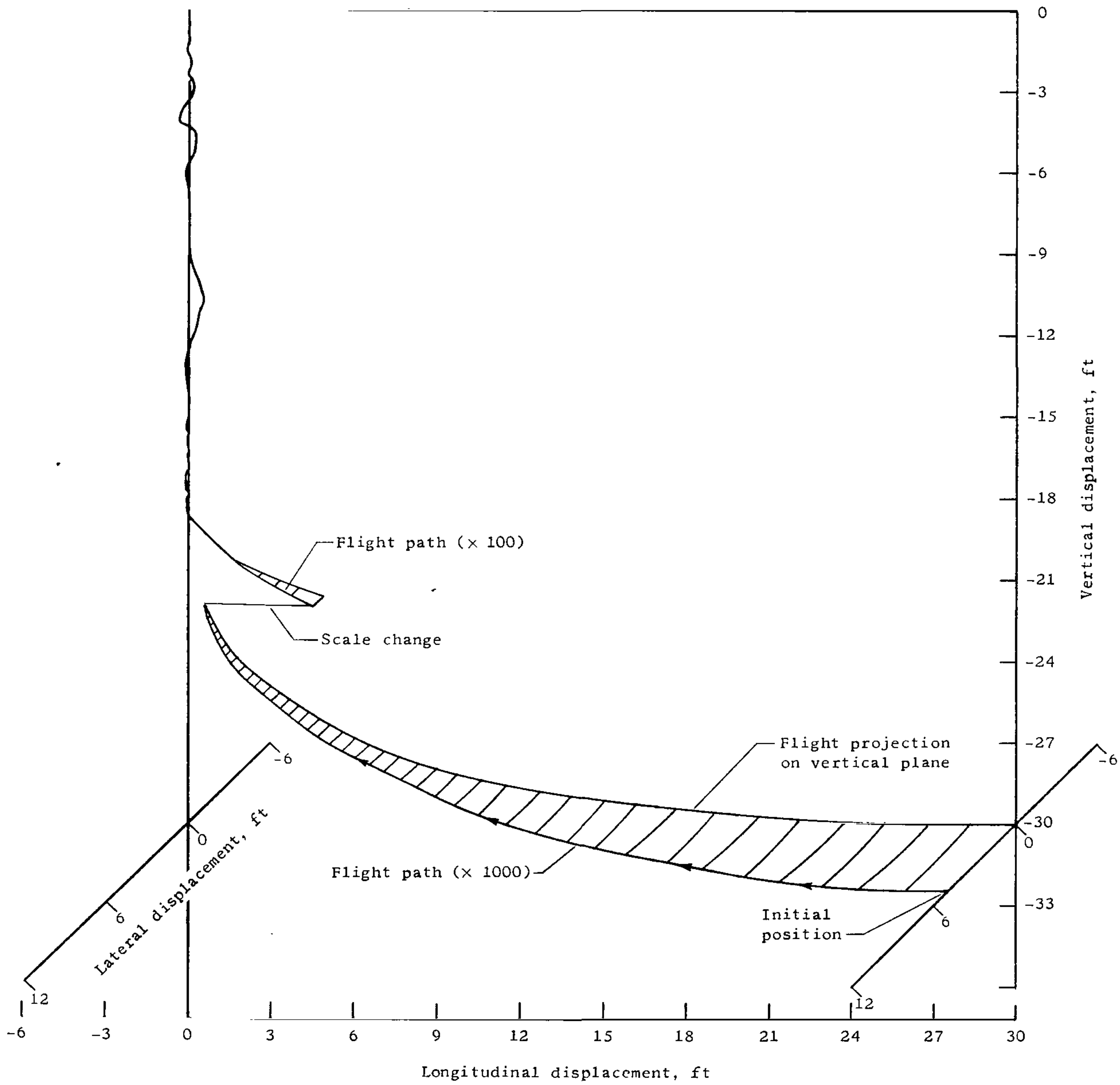


Figure 14.- Three-dimensional plot of flight III rendezvous. Pilot C.

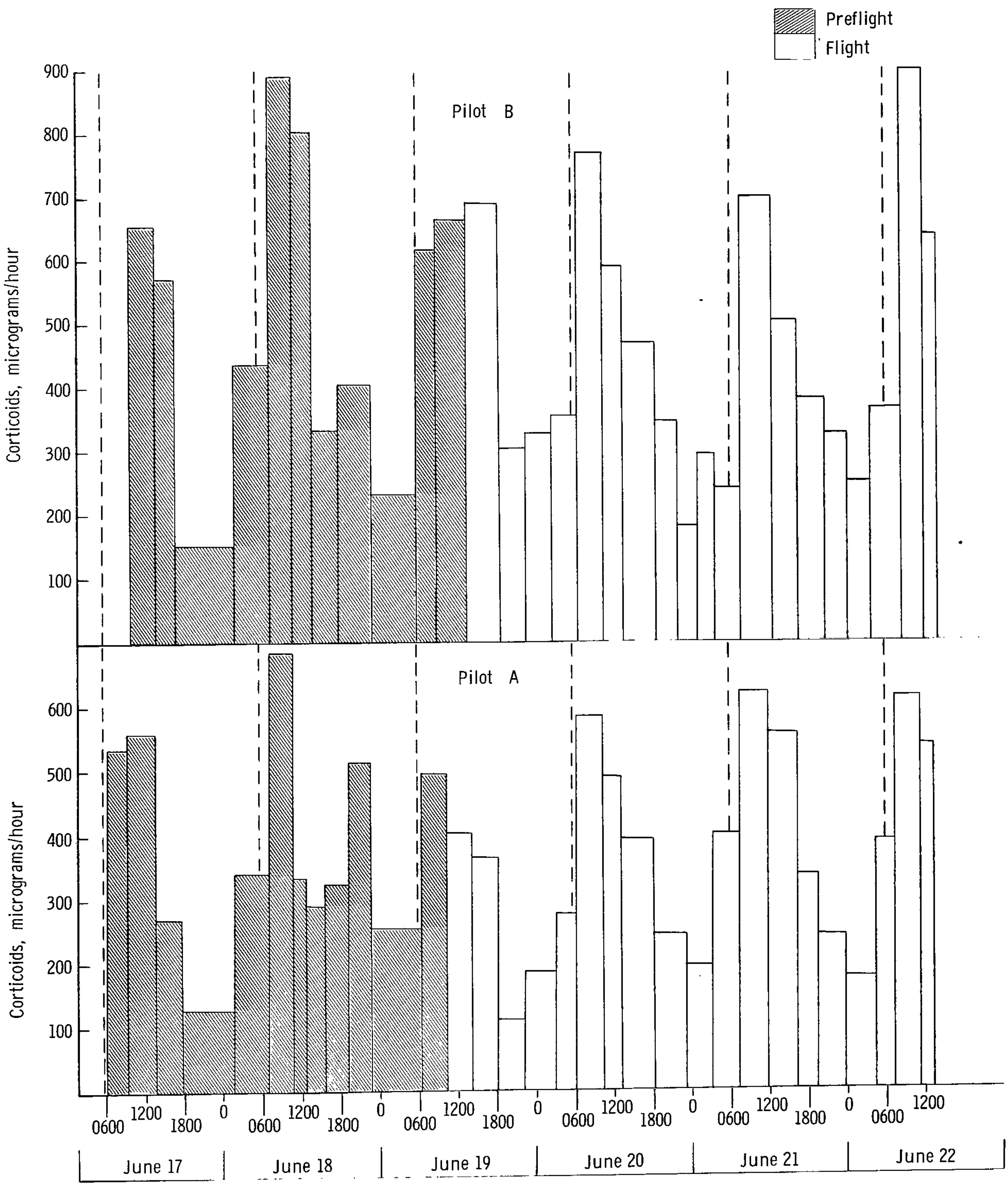


Figure 15.- Corticosteroid results of flight II.

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